MEMOIRS OF THE GEOLOGICAL SURVEY.

ENGLAND AND WALES.

THE GEOLOGY OF

NORTH CLEVELAND.

(EXPLANATION OF QUARTER-SHEETS 104 S.W. S.E., NEW SERIES, SHEETS 34, 35.)

BY

GEORGE BARROW, F.G.S.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HER MAJESTY'S TREASURY.

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PREFACE.

The present Memoir describes the geology of the coast of Yorkshire from the mouth of the Tees to beyond Whitby, and of the Cleveland Hills and Moors. In no part of England is the relation of the surface topography to the nature of the underlying rocks more instructively displayed than in this district; nor can the succession of a considerable part of the Jurassic series of formation be anywhere more advantageously examined than along the admirable coast-sections of Yorkshire. Of much interest also are the glacial deposits, and the evidence that they in large measure conceal an older topography, and that since their formation deep ravines have been excavated in them as well as in the solid rocks underlying them.

The economic geology of the district described in the Memoir is also of considerable importance. From the ironstone mines of Cleveland nearly four and a half millions of tons of ore are annually raised. In recent years the discovery of salt-beds at the base of the Trias has started a new industry, and has given an additional impetus to the growth of this part of Yorkshire. This district also furnishes alum-shale and jet, the workings in which were formerly numerous.

ARCH. GEIKIE,
Director General.

Geological Survey Office,
January 30th, 1888.

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NOTICE.

The area described in the following Memoir was surveyed, under the superintendence of Mr. H. H. Howell, by Mr. G. Barrow. Two editions of the one-inch Map are published—one showing the drift, the other the ordinary (or "solid") geology only.

Of the six-inch Geological Survey Maps of the district four are published, viz., Sheets 7, 9, 20, and 32 (Yorkshire); four are engraving—Sheets 8, 17, 18, 19. Coloured MSS. copies of the remaining maps (Sheets 29, 30, 31) are deposited for reference in the Geological Survey Office.

The geological structure of the district is further illustrated by three sheets of Horizontal Sections, running in a general N. and S. direction. The most easterly section, near the coast, is Sheet 130; the others are Sheets 131 and 132.

H. W. BRISTOW,
Senior Director.

Geological Survey Office,
28, Jermyn Street, London, S.W.,
January 24th, 1888.

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CHAPTER I.

INTRODUCTION.

It is proposed in the following pages to give a brief outline of the geology of the area included in Sheet 104. This consists of about 150 square miles, and is familiarly known as Cleveland; but it is really only the northern half of that district. From it almost the whole of the well-known Cleveland Ironstone is obtained.

The chief towns are Whitby, Guisborough, Redcar, Loftus,* Saltburn, and Marske, but none of them are of any great size. Whitby, Redcar, and Saltburn are best known as watering places; still the northern and western parts of this area are somewhat thickly populated, owing to the great influx of miners. Among the chief villages which have been considerably enlarged in this manner are Staithes, Skinningrove, Liverton, Brotton, and Skelton; while such places as Dunsdale and Boosbeck have sprung into existence only since the opening of the mines close by. The town of Whitby is indeed the only one in which the population has not been more than doubled owing to the great iron industry of Cleveland. About the central part of the district, which is sparsely populated, are a few villages of quite an agricultural character, such as Lythe, Hinderwell, Easington, and Moorsholme, while the southern portion is mostly moorland.

The drainage of the country is effected by two sets of streams. Those draining north flow direct into the sea, while the others flowing southward mostly join the Esk and so reach the sea. The two small streams in the south-west corner of the map, which drain Lonsdale and South Leven valleys, join the Leven at Kildale and then flow into the Tees. It will be seen from the foregoing that a watershed crosses the southern part of this area, its course being by Guisborough Moor, Danby Low Moor, and Rousby High Moor, leaving the map due south of Ugthorpe. The country to the north of the watershed is drained by a series of comparatively small streams, flowing independently to the sea. Of these the first two debouch at East Row and Sandsend. They really drain but one valley, which is defined by Lythe, Mickleby, Ugthorpe, and the southern limit of the district. These two streams are kept apart by a ridge of Glacial deposits, which has the effect of dividing a single pre-glacial valley into two nearly equal parts. Overdale Beck, north of Lythe, calls for no special notice. At Runswick Bay no less than three small streams enter the sea, but from its size it is at once evident that

* Lofthouse on Ordnance Maps.

this beautiful amphitheatre does not owe its origin to them; its real mode of formation will be explained later on in describing the drift deposits and the phenomena of pre-glacial valleys. A considerable area is drained by Staithes Beck, which carries off the combined waters of Borrowby, Rousby, and Easington Becks. Skinningrove Beck, which splits into two main branches at Loftus, drains the greater part of Moorsholme, Stanghow, and Liverton Moors. The two streams that enter the sea at Saltburn both rise on comparatively low ground, one in the peat-moss near Boosbeck, the other on Eston Moor quite at the west edge of the district here described.

A glance at the map shows that it is naturally divided into two areas, the main table-land with its two outlying portions of Eston and Upleatham hills, and the valleys and great plain in the north-west. These two divisions correspond to the main geological formations, the Oolite and the Lias. The table-land, which is only some 200 feet high at its eastern extremity, gradually rises to the west, till at the highest point of the watershed on Guisborough Moor it attains an elevation of 1,078 feet. Most of the summits of the Oolitic hills near, and west of this point rise to a height of more than 1,000 feet. The deeper valleys that indent the more elevated area, expose a considerable thickness of Liassic strata.

In consequence of the drift obliterating all but the most strongly marked geological features of the country, the general scenery is somewhat disappointing. The great escarpment about Guisborough and passing round into Kildale, shows how beautiful it would be were this cover absent. But while obliterating the general views, the drift has produced a class of scenery which is almost a characteristic of North Cleveland. The drift deposits have blocked the old pre-glacial valleys and forced the streams to form new channels, which, strangely enough, they have cut out through deep gorges in the solid rock, in preference to re-excavating their old course through the Boulder Clay. The dense vegetation with which their rocky sides are clothed cause these gorges to be the most picturesque parts of the district. They, moreover, show clearly how short a time is required for a small stream to scoop a deep channel; and that the breadth of a valley, not its depth, is the chief clue to its antiquity.

To the geologist, however, the greatest interest attaches to the bold cliffs that fringe the coast, for it is in them that the celebrated sections of the Lias occur, in which the beds may be studied and measured foot by foot, and all the chief fossils collected. To the extreme east these cliffs are some 300 feet high, consisting of Lower Oolite sandstones and shales, with, at their base, about 100 feet of Upper Lias; decreasing in height as we approach Whitby, the amount of Lias becomes less and less till the base of the Oolites comes down to high water-mark, and the East Cliff is only some 200 feet high.

Between Whitby and Sandsend the phenomena attending the filling up of the pre-glacial valleys by drift deposits, may be well seen, while upon reaching Lythe Point, the section is approxi-

mately the same as that east of Whitby. From the former place to Rosedale Wyke (Port Mulgrave) the cliff consists of Upper Lias, capped with a varying thickness of Oolites, generally some 50 feet. After passing Overdale Wyke, the beds rise steadily as far as Boulby or Rockcliff. This magnificent cliff, which is nearly 700 feet high, shows a clear section of no less than 600 feet of Lias. Beyond this point both the cliffs and the beds rise and fall with the change of coast line as far as Saltburn. Between this place and Redcar they are entirely composed of drift deposits, and decrease in height as the latter place is approached. Before reaching this latter town the cliffs have sunk so low as to have ceased to exist. Though not forming cliffs here, there is a large outcrop of the Lias in the great reefs or scars between high and low water-mark; and nearly the whole of the Middle Lias and most of the Lower can be studied in them.

The rocks composing the surface of the district described in this Memoir consist of the Lower Oolites and the Lias, the former being capped along a synclinal axis by the Kellaways Rock of the Middle Oolite; the latter having at its base the Rhætic Beds and part of the New Red Marl.

The following are the geological formations that occur in the district:—

TABLE OF FORMATIONS.

Post Tertiary	Recent and Post-Glacial.		Blown Sand.
			Marine Warp.
			Alluvium.
			Peat.
			Raised Beach.
	Glacial		Upper Boulder Clay.
			Sands and Gravel.
			Lower Boulder Clay.
Tertiary?	Igneous		Whinstone (Augite-andesite)
Secondary	Middle Oolite		Kellaways Rock.
	Lower Oolite		Cornbrash.
		Inferior Oolite	Estuarine Series.
			Grey Limestone Series.
			Estuarine Series.
			Eller Beck Bed.
			Estuarine Series.
			Dogger or Top Bed.
	Upper Lias		Alum Shale.
			Jet Rock.
			Grey Shale.
	Middle Lias		Ironstone Series.
			Sandy Series.
	Lower Lias		Lower Lias Shales, &c.
	Rhætic or Penarth Beds		Avicula contorta Shales and Tea-green Marls.
	Trias		Red Marls.

CHAPTER II.

TRIAS AND RHÆTIC BEDS.

Trias.

New Red Marl.—The lowest beds observed in the area here described are some red marls, intersected with irregularly bedded gypsum that outcrop at the base of the small bank on which the railway runs at Lazenby Station. The top of this little bank consists of "Tea-green" Marl, so that only a few feet of the New Red is exposed here. Some drains showed red and green marls, nearer to the Tees.

A boring near Westfield House, on Coatham Marsh, after penetrating the basement beds of the Lower Lias, was continued to a depth of 167 feet into Red Marl.

Although only quite the upper beds of the New Red Series crop out in this area, interest now attaches to the formation owing to the occurrence in the adjoining district to the west of a vast bed of salt. This has been proved to lie quite at the base of the New Red Sandstone, in fact, practically at the junction of that series with the underlying Magnesian Limestone. Till quite recently, all the efforts to prove this salt were confined to the immediate neighbourhood of Middlesbrough and Port Clarence; but Messrs. Bolckow and Vaughan have lately put down a boring close to the river at Eston Station, in which the salt, about 100 feet thick, was found at 1,674 feet from the surface, the New Red Marl being about 400 feet thick.

As this boring commences somewhere between 100 and 200 feet from the top of the New Red, it gives a nearly complete section of the whole series. The earlier trials of Messrs. Allhusen, near the Tees, show that it is very dangerous to assert positively that the salt will be found at any one special place; still, as it has been found over an area of several square miles, it probably exists over a considerable area between Redcar and Middlesbrough.

Rhætic (or Penarth) Beds.

The only outcrop of the Rhætic Beds in this area is that of the Tea-green Marl referred to above. These beds were, however, pierced in the well-known Eston Gypsum pit, a little to the west.* From evidence obtained in the Northallerton district, we are

* The Yorkshire Lias, p. 31.

inclined to put the top of the Rhætic Beds a little higher than Messrs. Tate and Blake have done, making the section as follows :—

	Ft.	In.
Superficial beds and Lower Lias - - -	170	6
Rhætic Beds.		
*Light blue close-grained limestone - - -	2	0
Shales - - - - - -	3	8
Siliceous band - - - - -	1	4
Dark grey shale with pyritous sandstones - - -	7	0
Black shale with *Avicula contorta* and *Isodonta Ewaldi* -	3	0
Black hard shale with thin plates of gypsum in the joints -	3	1
Tea-green Marls - - - - -	9	6
Red Marls (Trias).		

The first bed here given, the light blue limestone, is most probably the one so well seen near Crosby Cote, Northallerton.†

The pyritous sandstones in the dark grey shale are characteristic of the Rhætic Beds in this area. They consist of fine siliceous matter, with little grains of pyrites distributed through the mass, and contain casts of *Isodonta Ewaldi* in great numbers. They may be studied in the little stream at Ormesby Station.

The boring near Westfield House, referred to above, proved the Rhætic Beds, the account being as follows :—

	Ft.	In.
Hard Band.		
Dark shale, sulphur, and hard bands - - -	12	0
White and grey post (Tea-green Marl) - - -	9	0
	21	0

* Probably "White Lias."

† *See* Memoirs of the Geological Survey, Explanation of Quarter-sheet 96, N.W.

CHAPTER III.

LIAS.

Lower Lias.

The whole of the Lower Lias may, for convenience, be divided into two parts, the lower composed of shale, with calcareous bands of various thickness and purity, the upper of shales, with rows of ironstone nodules or "doggers." The lowest beds of the Lias are never seen at the outcrop, but they have been proved in two borings, one at Coatham, the other in the boring on Coatham Marsh, referred to before. This last gives the following section :—

	Ft.	In.
Clay	6	0
Blue shale, dogger band	75	0
Nodular band	1	6
Blue shale	1	8
Nodular band	1	6
Blue shale	21	0
(*a*) Bastard post, grey	5	0
Blue shale, hard band	33	0
Rhætic Beds.		

It is most probable that (*a*) represents the *Pleuromya crowcombeia* limestone, well seen at Northallerton, with the little hard bands above and below it run together; but it is, of course, impossible to be sure of this. We found fragments of *Am. planorbis* in the spoil heap; but Messrs. Tate and Blake, who visited the spot much earlier, give the following list of fossils :—*

From a dark earthy limestone—

Ammonites Johnstoni.
——— *planorbis.*
Eucyclus elegans.
Cerithium tenuicostatum.
Lima gigantea.
—— *pectinoides.*
Ostrea [*Gryphæa*] *arcuata.*
——— *liassica.*
Pecten lunularis.
——— *textorius.*
Modiola lævis.
Pinna Hartmanni.
Pleuromya galathea.
Pentacrinus psilonoti.
Hemipedina Tomesii.

And from black friable shales associated with the limestone—

Cardinia ovalis.
——— *Listeri.*
Nucula navis.
Astarte cingulata.
Astarte obsoleta.
Unicardium cardioides.
Pholadomya Fraasii.
Rhynchonella plicatissima.

Above these beds are the shales with hard calcareous bands seen on the foreshore and in the scars about Redcar. They have been described in such minute detail by Ralph Tate,† who lived

* The Yorkshire Lias, page 44. † Ibid, pp. 48 and 49.

in the neighbourhood for some years, that only a short description of their outcrop will be given here.

Opposite the battery are some soft dark shales with small forms of *Gryphæa arcuata* and *Ammonites angulatus.* They dip North-west at an angle of 7°, a high dip for this district, but one which continues to increase rapidly seaward. The following fossils may be found here:—

Ammonites angulatus, Schloth.
Am. Johnstoni, Sby.
Gryphæa arcuata, Lam. (*incurva,* Sby.)
Cardinia Listeri, Sby.
Lima gigantea, Sby.
Pleurotomaria similis, Sby.
Plicatula liasina, Terq.

Seaward of these beds are some rather harder shales with hard calcareous bands, often almost composed of *Gryphæa arcuata,* and known as "Gryphite limestones." This fossil attains its finest development in these shales, and, in a small exposure, the thickness of one of these bands and the size of the *Gryphæa* in it would at once be sufficient to determine the horizon to which they belonged. The bands, being much hardened by sea water, form long scars or reefs opposite Redcar,* and thus afford fine opportunities for study when the tide is out. It is interesting to note the peculiar abundance of keeled Ammonites such as *Am. Bucklandi, Am. bisulcatus, Am. Turneri,* in consequence of which they are referred to the zone of *Am. Bucklandi.* In addition to these, the following fossils may be easily found at low-water:—

Gryphæa arcuata, Lam. (*G. incurva,* Sby.)
Cardinia Listeri, Sby.
Lima gigantea, Sby.
Hippopodium ponderosum, Sby.
Pleuromya galathea, Ag.
Avicula inæquivalvis, Sby.
Cardinia hybrida, Sby.
Unicardium cardioides, Phil.
Montlivaltia sp., &c.

For a detailed description of the scars formed by these beds see Tate and Blake, page 54 *et seq.*

There is an exposure of this part of the Lias at the foot of a small sand dune just west of Coatham. A rather thick bed of *Gryphæa arcuata* is seen; but, from the account given by Messrs. Tate and Blake, the sand has evidently covered up the greater part of this section within the last few years.

About a mile west of Marske, and opposite Red Howls, is an exposure of "Shale with hard bands," which can be seen only under favourable circumstances,† as it is so often sand-covered. Messrs. Tate and Blake give *Am. semicostatus* and *Am. bisulcatus* from these beds, and refer them to their zone of *Am. Bucklandi.*

Another alternation of shales and hard beds succeeds the strata described above, and this series Messrs. Tate and Blake have referred to the zone of *Am. oxynotus.*‡ Their outcrop is, for the most part, under water, or else under blown sand and Boulder

* The Flashes, East Scar, and Jenny Leigh's Scar, are formed of these beds.
† I made four visits to this spot without being able to see this outcrop.—G. B.
‡ The Yorkshire Lias, p. 72 *et seq.*

Clay. A small portion of them is, however, exposed in the "High Stone," from which Tate has obtained *Am. oxynotus*, but this is a most unsatisfactory section.

At Ayton, on the south bank of the Leven, where the road passes alongside the stream, shale with a thin hard band is seen dipping north-west. We obtained *Am. oxynotus*, and Messrs. Tate and Blake record *Am. gagateus*, so, from the complete section at Robin Hood's Bay, we know that we have here exactly the middle beds of the *Am. oxynotus* zone. The shale with thin hard bands seen in the old "Whin" quarry, west of Quarry House, near Ayton, evidently belongs to this portion of the Lower Lias.

Although the beds of this series are not actually seen, they were proved in the great sinking and boring at Osborne Rush, south of Eston Hill, the section of which was as follows :—

		Ft.	In.
	Shale, soft, with ironstone nodules	156	2
(1).	Dark shale and scars of post	20	2
	Strong grey metal and post girdles	4	0
	Post girdle	0	3
	Grey metal with post girdle	2	1
	Soft blue metal	5	0
	Grey metal	11	6
	Strong grey metal	4	0
	Blue shale	13	6
	Strong dark blue metal	0	6
	Blue shale	12	0
	Dunstone, mixed, with a little ironstone	1	6
	Blue shale	66	6
	Strong metal stone, mixed with post	17	0
	Blue plate	30	0
	Strong metal stone with post	6	0
	Blue shale	66	0
	White post ?	6	0
	Metal parting	2	0
	White post ?	1	6
	Blue metal with post girdles	37	9
	Total below (1)	426	3

It is just possible that the "white post" marked (?) is the same as the "bastard grey post" (*a*) in the Coatham boring, in which case this section stops exactly at the top of the Rhætic Beds, and proves the hard band series of the Lower Lias to be 425 feet thick, a fact rendered very probable by other evidence. From the general character of the beds above (1), there is no doubt that they belong to the zone of *Am. armatus*.

The upper portion of the Lower Lias in this district consists of about 300 feet of shale, with rows of ferruginous nodules, or "doggers" at intervals. These beds are divisable into three series. The upper part consists of 80 ft. of sandy shales, with ironstone nodules containing *Am. fimbriatus* and *Am. capricornus*, and represents the lower part of the zone of *Am. capricornus* of Tate and Blake. The middle beds are softer than the above, but contain ironstone nodules, and also *Am. Jamesoni*, &c., and belong to the zone of *Am. Jamesoni*. The base consists of a series of soft dark

argillaceous shales with much pyrites; *Am. armatus*, &c.; and forms the sub-zone of *Am. armatus*.

On the coast the lowest beds are seen at the north edge of High Stone, and again at the extreme south edge of Coatham Scars; but these exposures are of little interest, being very obscure. The higher beds, however, are frequently seen between Staithes and Saltburn, and the following sections have been measured in them, in descending order.

Section of the upper beds of the Lower Lias just west of Staithes.

		Ft.	In.
	Lowest *Gryphæa*-bed, (Middle Lias).		
	Shale with nodules, *Am. capricornus*, &c.	28	0
	Nodular band, *Am. fimbriatus*.		
	Shale, rather sandy	7	0
	Nodular band, *Pecten lunularis*.		
	Sandy grey shale	5	6
(*a*.)	White ironstone band, shelly	1	0
	Shale, with nodular* bands	24	0
	Nodular band, *Am. fimbriatus*.		
	Shale	5	6

The scars immediately below the last band are rather softer, and *Am. capricornus* was not found. Fossils occur in little heaps, *Rhynchonella tetrahedra* (?), *Pecten lunularis*, *Pecten æquivalvis*, *Gryphæa obliquata*, *Myacites* (sp.) being the most common. Isolated specimens of *Hippopodium ponderosum*, and *Pholadomya Beyrichi* (?) are also easily found. There is much fossil wood, these beds being in fact rich in organic remains, thereby contrasting with the beds above. The series could not be measured further owing to the talus at the foot of the cliff.

Proceeding westward along the shore the strata continue to rise, and the lowest beds are seen under Rockcliff. From this point they descend again to Hummersea, where the following section was measured :—

		Ft.	In.
	Nodular ironstone band, *Am. fimbriatus*	0	3
	Micaceous shale, *Am. fimbriatus*, *Am. capricornus*	7	0
	Nodular ironstone band, *A. capricornus*, *Pecten lunularis*, *P. æquivalvis*, &c.	0	5
	Shale	6	0
(*a*.)	White ironstone band with fossiliferous base	1	0
	Shale	5	0
	Nodular band, cone-in-cone structure	0	6
	Shale	3	6
	Nodular band	0	3
	Shale, very few fossils	20	0
	Nodular band, *Am. fimbriatus*, *Am.* sp.	0	3
	Shale, Encrinite fragments	6	0
	Nodular band.		
	Shale	6	0
	Nodular band, *Myacites*, sp., *Belemnites elegans*.		
	Shale	5	6
	Nodular band, many fossils, small gasteropods.		

* These nodules are small and peculiarly round, often containing casts of *Am. capricornus*.

	Ft.	In.
Shale, few fossils Nodular band.	8	6
Shale, few fossils Nodular band.	8	0
Shale Nodular band, *Am. fimbriatus, Pecten lunularis, Bel. elegans, Myacites*, sp.	5	0
Shale Scattered small nodules.	7	0
Shale, *Pecten æquivalvis, Bel. clavatus, Gryphæa obliquata* Dispersed nodules.	10	0
Shale, *Am. Jamesoni, Rhynchonella plicatissima, Pinna folium, Pholadomya decorata*, &c.	12	0

The bed (*a*) is here the same as the bed (*a*) in the Staithes section, and is continuous over a great area,* so from the two we can make a complete section of all the Lower Lias beds seen in the cliff.

Beds, about 20 feet below these, crop out at the foot of Rockcliff, and there may be found in them, *Am. brevispina*, in small pyritous casts; *Belemnites clavatus, Pinna folium, Gryphæa obliquata*, and several of the commoner fossils of this part of the Lias.

Between Hummersea and Skinningrove, only the top beds of the Lower Lias are seen along the foreshore, but the change in direction of the coastline beyond, soon brings up lower beds till, under Huntcliff foot, the scars are composed of beds little above the shales seen at the foot of Rockcliff.

At the foot of Huntcliff *Am. Jamesoni, Am. brevispina, Bel. elegans, Pinna folium, Hippopodium ponderosum, Plicatula spinosa, Gryphæa obliquata*, &c., may be found in considerable numbers. Approaching Saltburn these beds sink beneath sea-level, and the higher beds are mostly concealed by Boulder Clay. There is no exposure of them west of Saltburn, in the cliff, which consists entirely of Glacial deposits or Blown Sand. But they crop out again in Coatham Scars; the greater part of the shales upon which the pier stands, belongs to the upper half of the Lower Lias. Here, however, the rocks are so covered by sea-weed, limpets, &c., that it is impossible to make a satisfactory examination of them.

Turning inland, sections below the base of the Middle Lias are rare, as the Drift usually creeps up the hill-sides as far as, or above that horizon.

Shales with ironstone nodules, often containing *Am. capricornus*, are seen in Yearby Wood, the incline from Dunsdale mines giving a clear section of them. Further west, just before reaching the Wilton and Guisborough road, is a considerable opening in these beds, probably to obtain materials for brickmaking. It is wrongly called "Sandstone Quarry" on the six-inch map.

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* *See* Memoirs of the Geological Survey. Explanation of Quarter-sheet 95, N.W., page 7.

Small exposures occur in Castle Gill and Waterfall Gill; and these shales, being bare of drift along the foot of Eston Hill, have been cut into in several places in the course of mining operations.

The lowest beds of this series were sunk through in Osborne Rush pit, as mentioned on page 8, but there is no actual exposure on the north side of the Guisbrough valley.

To the south, near Hutton Hall, and again in the steep railway bank near Pinchinthorpe, the highest beds of the Lower Lias are seen. The scars seen at the foot of the great bank below Roseberry Topping belong to this horizon; the shales at the base of the great hill that the Dyke traverses, being somewhat lower. By following the Dyke to the west, the whole of this portion of the Lower Lias is passed over, the first indurated bands being seen in the quarry quite at the west edge of the map. So many openings have been made that the shales can be examined satisfactorily. About the whin quarries, due south of Roseberry Topping, are several exposures of the shales with *Am. capricornus.*

In the stream near Easby Mill, under Captain Cook's Monument, shales are seen containing *Am. Jamesoni*, and following up the stream, a nearly complete section is passed over till the base of the Middle Lias is reached at the beautiful little waterfall, "Old Meggison,"* not far from Kildale Village.

The following fossils have been collected, along the coast between Saltburn and Staithes, from the shales of the Lower Lias above the hard band series:—

Pentacrinus.
Rhynchonella tetrahedra, Sby.

Gryphæa cymbium, Lamk.
Hippopodium ponderosum, Sby.
Leda minor, Simp.
Leda galathea, D'Orb.
Lima pectinoides, Sby.
Modiola scalprum, Sby.
Pecten æquivalvis, Sby.
,, *lunularis*, Rom.
Pholadomya ambigua, Sby.
,, — *decorata*, Zeit.
Pinna folium, Y. & B.
Plicatula spinosa, Sby.

Unicardium cardioides, Phil.

Ammonites Bechei, Sby.
,, *brevispina*, Sby.
,, *capricornus*, Schloth
,, *fimbriatus*, Sby.
,, *Jamesoni*, Sby.
,, *obsoletus*, Simp.
,, *trivialis*, Simp.
,, *raldani* (?), D'Orb.

Belemnites apicurvatus, Blainv.
,, *clavatus*, Blainv.
,, *elegans*, Simp.

Middle Lias.

The Middle Lias in this district is divisible into two parts, the upper, known as the Ironstone Series, the lower, the Sandy Series.

Sandy Series.—The Sandy Series consists of alternations of hard sandy shales and thin micaceous, calcareous, and ferruginous

* This waterfall is one of the gems of Cleveland.

sandstone, the whole marked by the extreme abundance, along certain lines, of *Cardium truncatum, Gryphæa* (*Ostrea*) *depressa*, &c.

These beds rise from the sea just east of Staithes, the upper part forming the long flat scar known as Penny Stile. Here *Am. margaritatus, Cardium truncatum* and many small fossils may be found. The strata rise to the west, and the upper beds can be carefully measured as far as the beach in front of the village, where the small beck has denuded away part of the series. There is, however, no trace of any fault here, as has so often been asserted; a fact that can be conclusively proved at low-spring-tides.

The rest of the series can be measured and carefully examined in Staithes Nab, the whole giving the following section.

Section of Sandy Series at Staithes.

	Ft.	In.
Finely laminated, calcareous sandstone, *Am. margaritatus Cardium truncatum, &c.*	0	10
Hard sandy shale, slightly calcareous	5	0
Finely laminated calcareous sandstone	1	0
Hard sandy shale	4	6
Sandstone, fissile, with bands of *Cardium truncatum, Am. margaritatus, Avicula cygnipes, Dentalium giganteum*	13	0
Sandy shale	4	6
Hard laminated sandstone, layer of *Gryphæa depressa*	1	2
Sandy shale	1	3
Hard sandstone, shelly band above and below	1	3
Shale with sandy ferruginous nodules *Am. capricornus*	5	3
Hard sandstone with several shell bands	4	3
Sandy shale	2	0
Ferruginous and micaceous sandstone	0	10
Hard sandstone; *Am. capricornus, Gryphæa depressa, Avicula inæquivalvis*	2	0
Hard sandy shale	7	0
Sandstone	2	0
Shale	1	6
Flaggy sandstone	3	0
Harder sandstone with three oyster bands	3	0
Sandstone softer towards the lower part, with thick bed of *Gryphæa depressa** at base	5	6
Softer shales of Lower Lias.		
Total	68	10

Or nearly 70 feet.

These beds may be followed up Staithes Beck, past Dalehouse, and up Rousby and Easington Becks, sections being frequent and clear, from which most of the characteristic fossils may be obtained. The greater portion of the Sandy Series forms the bearing rock of the cliff from Staithes nearly to Boulby Alum Works. Though clearly seen as far as Hummersea they are quite inaccessible till the latter place is passed, when the massive bed containing the bands of *Gryphæa* (*Ostrea*) comes down to about

* This bed yields many fossils; the chief are *Am. capricornus, Gryphæa depressa, Avicula inæquivalvis*, and a small variety of *Cardium truncatum*.

high-water mark, and continues approximately in that position as far as Skinningrove. About here these beds are fairly accessible for fossil collecting. Beyond Skinningrove a nearly complete section is seen in Cattersty Beck, after which clay covers the entire outcrop as far as Huntcliff Mine, where, as it only re-appears in the cliff-face, it is quite inaccessible. Keeping this latter position as far as the most northerly part of Huntcliff, the Sandy Series again passes inland under Drift, two sections being, however, shown by the cutting through the clay in Saltburn Gill; the first of these is near the base; the second is the exact top of the series. This last section is figured by Messrs. Tate and Blake (Yorkshire Lias, p. 111), but the amount of disturbance is really very slight, and is what constantly occurs at the junction of a thick bank of Boulder Clay with the rocks beneath; it may be glacial action, but we believe it to be due solely to the sliding of the heavy clay bank above. In Skelton Beck the first section is exactly at the south boundary of Saltburn Gardens, and here the middle of the series is seen. Under Rushpool, slightly higher beds crop out, and from this point as far as Skelton Mill the bed and sides of the stream are composed of the highest part of the Sandy Series. Throughout the whole distance fossils may be collected; near Marske Mill in particular a considerable variety of species are to be found, such as *Am. margaritatus, Discohelix aratus, Dentalium elongatum, Chemnitzia Blainvillei, Avicula inæquivalvis, Cardium truncatum, Pecten lunularis,* and several others.*

On the three other sides of Hob Hill, the country is entirely covered by Drift, and the outcrop can be only approximately fixed, the same condition of things prevailing round Upleatham Hill. In the higher part of Yearby Wood, called the Folly, several opening have been made in thin sandstones containing *Cardium truncatum,* and from this point westward the Sandy Series is practically exposed in every small stream, overlooking Wilton Castle and the surrounding district. The road over the escarpment to Wilton gives the following section:—

	Ft.	In.
Shales, ferruginous and sandy	—	
Sandstone, with shell bands	2	6
Rubbly sandstone, breaks up small	6	3
Sandstone, very hard, finely laminated	1	8
Sandstone, soft	9	0
Sandstone, hard, laminated, shelly in middle	1	0
Sandy shale	6	0
Hard sandstone, marly bands, base not seen, (about)	30	0

This shows only the upper part clearly; but it is at once apparent that the whole series is far thicker than at Staithes, and still more so than in the district just east of Whitby;† there is besides a distinctly more arenaceous character in the beds here.

* See The Yorkshire Lias, p. 135.

† Geological Survey Memoir. Explanation of Quarter-sheet 95, N.W.

A few yards west in Waterfall Gill the following section was measured :—

	Ft.	In.
Soft rubbly sandstone, *Avicula cygnipes, Cardium*, &c.	5	0
Harder sandstone, ferruginous nodules	6	0
Sandstone with ferruginous bands of *Cardium truncatum*	6	0
Soft rubbly flaggy sandstone	25	0
Hard marly beds	10	0

Small exposures of these beds occur at intervals about the Eston Mines. The great level-drift into the hill commences just at their base and cuts right through them, each stratum being penetrated in turn, as it is brought down by the dip, which is "into the hill." To the south, near Upsall Mill, is a small patch of the Sandy Series, brought up into the position shown in the map by the great Upsall Fault.

At the south end of Scugdale Slack, the deep hollow running up into Eston Hill, shales with thin ironstone-bands are seen, below which come thin flaggy sandstones evidently belonging to the Middle Lias. These sandstones make a good feature east and west, by which the outcrop is mapped; their position still further east is proved by the exposure of Lower Lias shale in the adit north of Howl Beck Mill. The outcrop on the north side of the fault can only be approximately calculated, as the sole evidence is the small opening in the sandstone beds cropping out, just under the road, in Tocketts Plantation, north-east of Guisborough. About Waterfall Wood the position of the Sandy Series is uncertain on account of the thick drift, but the railway cutting near Foxdale shows the lowest bands of sandstone with *Am. capricornus*, *Avicula inæquivalvis*, and the characteristic beds of *Gryphæa cymbium* var. *depressa*, Phil.

In Belman Bank the road passes over an almost complete section of the Sandy Series, from which most of the common fossils can be obtained, though principally in casts. Further west, openings have been made at intervals as far as the old "Hutton Mines." Here the incline and the various old paths give several clear sections of the upper beds, one of which is as follows:—

	Ft.	In.
Finely laminated, ferruginous sandstone	3	6
Soft sandstone and sandy shale *Cardium truncatum*	6	6
Hard lenticular sandstone in concretions	1	0
Flaggy sandstone and sandy shale	7	6
Hard thin micaceous sandstone	4	6
Sandy shales and thin sandstones, many fossils	6	0

Below this, the rubbish from the hill-sides has obscured the section, which throughout contains *Cardium truncatum* in great numbers.

The greater part of the long narrow hill to the west of Hutton Hall is composed of these sandstones and shales, which continue to form the steepest part of the bold escarpment flanking the great table-land of Cleveland. About Roseberry Topping and the great Whinstone Ridge, exposures are numerous. There is an outlier of the Sandy Series close against the whin quarries due

south of Roseberry, but the main outcrop, north and east of this, is covered by clay. In the road from Ayton Cottage to Captain Cook's Monument, the ruts show sandstone with *Cardium truncatum*, the outcrop being once more free of Drift as far as Burrow Greens. Just beyond this a small pre-glacial valley divides the outlier near Easby from the main mass of the series, which continues on the east side of the Drift-filled hollow, following round the great Oolitic outlier on which the monument stands. Emerging from its Drift-cover in the west bank of the Leven in Kildale, the Sandy Series gradually gets nearer the stream, till its base enters the water at Old Meggison, where it forms the top of the waterfall. The upper beds continue in the bank along which the new road has been cut, sections in consequence being numerous. This is an extremely pretty district, and worth a visit apart from the favourable opportunities for examining sections. Further east, the deeper parts of the dale are completely filled with gravel, and the Sandy Series is lost sight of.

There is an isolated outcrop of these sandstones with *Cardium truncatum* at the seaward end of the Redcar reefs, but it is very inaccessible and fossils can only be extracted with difficulty. Indeed, its only point of interest is the fact of its occurrence in this position, as it is strongly suggestive of some great fault out to sea cutting off all the Liassic beds, and bringing up the New Red Series.

Ironstone Series.—The beds last described are succeeded by a series of shales with ironstone bands of varying thickness, known as the Ironstone Series. The most easterly exposure is at Kettleness, where, owing to its distance from any railway station,* all the typical fossils of this horizon may still be easily collected, the ground not having been much searched. The following detailed section was measured at Kettleness Point.

		Ft.	In.
Thin cherty bed with nodules resting on shale; *Am. spinatus; Bel. breviformis; Pecten æquivalvis*, etc.		3	0
Thin cherty bed with ironstone nodules; *Am. spinatus; Bel. breviformis; Pecten æquivalvis*		0	4
Hard sandy shale, with nodules†		4	6
Ironstone band		0	3
Shale rather sandy		1	6
Ironstone; *Am. spinatus; Pecten æquivalvis*, &c. — 1 ft. 10 in.	Main Seam.	6	0
Shale, *Pecten æquivalvis* — 2 „ 0 „			
Shaly ironstone — 2 „ 2 „			
Shale with occasional fragments of fossil wood		1	6

* A station, on the Whitby and Redcar line, has lately been opened here.

† From this bed, Messrs. Tate and Blake record the following fossils:—*Am. spinatus, Am. ferrugineus, Chemnitzia Blainvillei; Turbo cyclostoma, Dentalium elongatum, Arcomya arcacea, Inoceramus substriatus, Leda graphica, Leda subovalis, Leda galathea, Macrodon Buckmanni, Astarte striatosulcata.*

	Ft.	In.
Ironstone 2 inches Shaly stone 8 „ Ironstone 7 „	1	5
Ferruginous shale, fucoidal markings	1	2
Ironstone band, many fossils	0	8
Ferruginous shale	1	6
Ironstone	0	4
Shale, *Pecten æquivalvis, Pleuromya costata*	1	0
Ironstone	0	3
Shaly ironstone, *Pleuromya costata*	0	10
Shale	1	2
Ironstone band, *Am. clevelandicus* (*?*) Y. & B.	0	6
Shale	7	0
Ironstone band	0	3
Soft sandy micaceous shale	5	0

The small *Am. clevelandicus* (*?*) was a bad specimen, but there could be little doubt as to its species. Messrs. Tate and Blake and Dr. Wright have called this *Am. margaritatus*; but the two fossils occupy different horizons and seem to me to be distinct species, though Dr. Wright adopts the views of the previous authors. Their zone of *Am. spinatus* must have its base just above the ironstone where the former Ammonite is found, the beds below belonging to their *Am. margaritatus* beds. The ironstone composing the Main Seam is here of poor quality, containing an average of about 26 per cent. of iron. It was, however, torn up off the scars, and shipped to the Tyne, but it was not thought to be worth mining, and consequently has not been followed into the cliff. Below the Main Seam, there occur in the district where the ironstone is best developed three other seams, and two of them must be represented in the above section, but they are so split up by shale, as to be almost unrecognisable.

Immediately under Kettleness village, is a sharp local synclinal running north and south, in consequence of which the Ironstone Series disappears under the Grey Shale for a short distance, but reappears in Redscar Hole, forming a semicircular patch on the scars. *Am. spinatus; Bel. breviformis; Rhynchonella tetrahedra, Pholadomya ambigua, &c.*, being found here.

The scars for some distance are formed of Upper Lias Shales, the next outcrop of the Ironstone Series occurring in the small weed-covered scar of Lingrow Knock. The first line of ferruginous nodules with *Am. spinatus* is seen here at low spring-tides. A fault of 40 feet throws the beds down to the west, to reappear in Brackenberry Wyke, where the Main Seam has been quarried or dug away to a considerable extent. From this point nearly to Staithes, the Ironstone Series forms the scars and base of the cliff. Commencing at Old Nab, and following the beds as they rise, the following section may be made out.

Section of the Ironstone Series at Staithes.

		Ft.	In.
Earthy ironstone nodules, *Pholadomya ambigua*, &c.		0	3
Shale		1	3
Thin laminated cherty bed		0	6
Sandy shale, rather hard		2	0
Shaly ironstone		0	6
Grey sandy shale		4	0
Ironstone, fucoidal markings at top 2 ft. 6 in. Shale 1 „ 2 „ Ironstone 2 „ 6 „	Main Seam	6	2
Shale, ferruginous		3	6
Ironstone 0 ft. 3 in. Shale 0 „ 9 „ Ironstone 0 „ 3 „ Shale 0 „ 4 „ Ironstone 0 „ 4 „ Shale 0 „ 8 „ Ironstone 0 „ 7 „ Marly shale 0 „ 9 „ Ironstone 0 „ 6 „	Pecten Seam. Very full of shells especially *Pecten æquivalvis*	4	5
Shale		2	7
Ironstone, *Am. margaritatus* (*A. clevelandicus*, Y. & B.) Two-Foot Seam		1	9
Shale with occasional ironstone nodules		10	0
Ironstone		0	10
Shale		15	0
Ironstone, Avicula Seam		2	0
Shale with variable bed of ironstone, very fossiliferous		1	0
Shales, rather sandy, with rows of nodules or doggers		19	0
Ironstone, very fossiliferous. *Am. margaritatus*		0	6
Soft sandy shale		11	0
Sandy shale, rather hard, with ferruginous nodules		4	6
Thin sandstone, &c. of the Sandy Series.			
		90	9

This section may be summarised thus:—

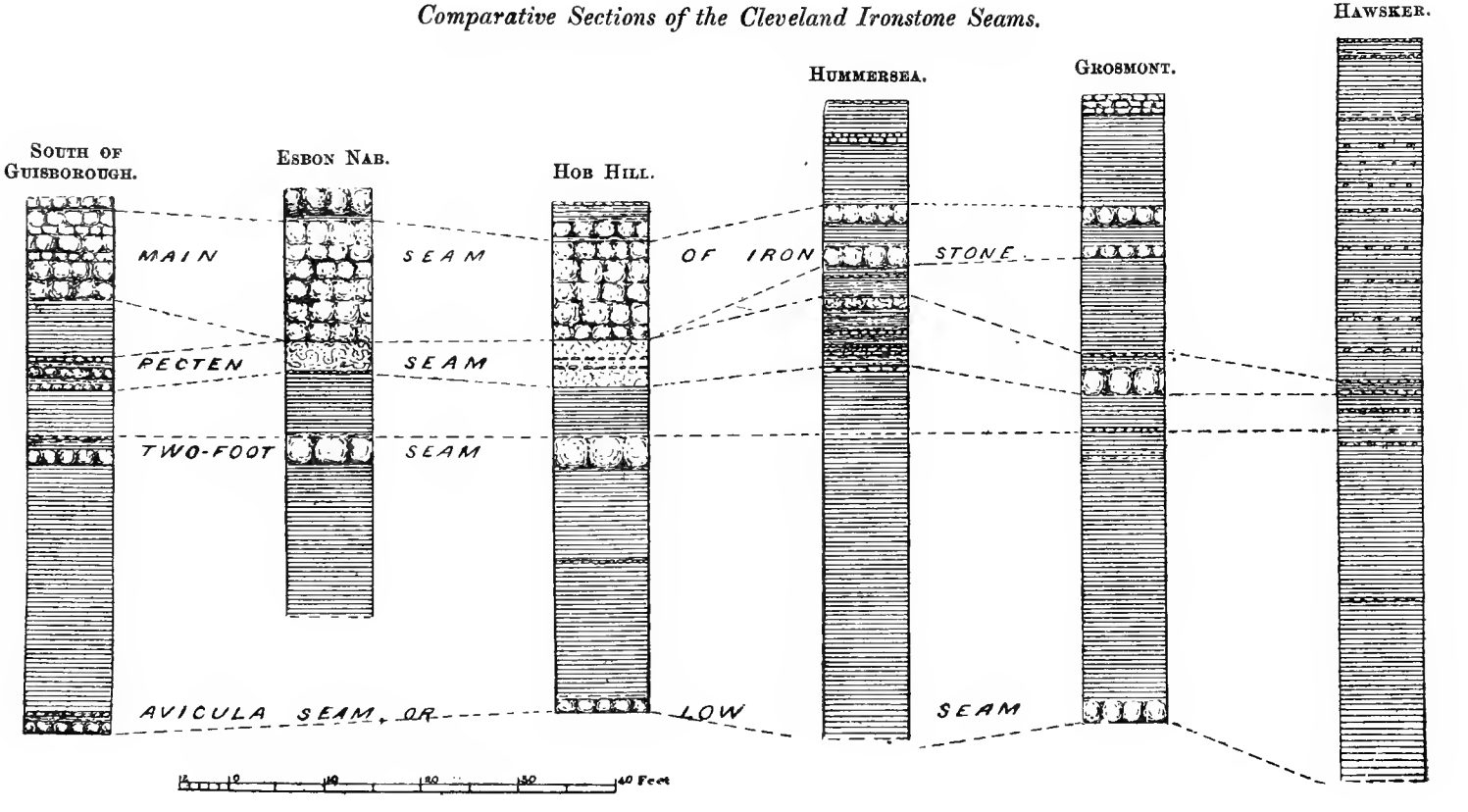
		Ft.	In.
Shale, &c.		8	6
	Main Seam	6	2
Shale		3	6
	Pecten Seam	4	5
Shale		2	7
	Two-Foot Seam	1	9
Shale		25	10
	Avicula Seam	2	0
Shale		36	0

The lower beds of shale are probably slightly thinner; the total thickness of the Ironstone Series, when measured with a long rope, was found to be 85 feet.

The Main Seam has been extensively worked to the south-east of Staithes, but it is now almost abandoned on account of its inferior quality. The other seams have not been worked at all up to the present time. After reaching Staithes, the outcrop of these beds turns due south, their upper limit being indicated by mining operations, the base line being only approximate. Where

Fig. 1.

Comparative Sections of the Cleveland Ironstone Seams.



these boundaries follow the line of the Oolite sandstones in Rousby Hill, there is no evidence of their exact position, owing to the great mass of Boulder Clay. But Rousby and Easington Becks show both limits of the Ironstone Series, a very clear section occurring in the latter stream, just at the mouth of Grinkle Mine.

The section is as follows:—

		Ft.	In.
Two laminated bands with shale, *Pholadomya ambigua*, &c. (section not clear)		5	0
Ironstone - 3 ft. 3 in. Shale - 1 „ 5 „ Ironstone 2 „ 2 „	Main Seam	6	10
Shale -		3	0
Ironstone - 0 ft. 4 in. Shale - 0 „ 9 „ Ironstone - 0 „ 5 „	Pecten Seam? full of shells	1	6
Ferruginous shale		2	0
Ironstone		0	9
Ferruginous shale		4	3
Ironstone, Two-Foot Band		1	3

The exact representative of the Pecten Seam may include beds below those bracketed, but the masses of shells only occur in these three.

Further north, several borings were put down to prove the position of the Main Seam; the details are, however, devoid of geological interest.

The Ironstone Series reappears in the face of the cliff under the boiling houses of the Boulby Alum Works, and the old road, now slipped away, gave the following section of the Main Seam:—

		Ft.	In.
Dogger		0	$3\frac{1}{2}$
Ironstone - 3 ft. 4 in. Shale - 0 „ 6 „ Ironstone - 3 „ 1 „	Main Seam	6	11

Though all the beds are visible in the cliff as far as Hummersea, they are quite inaccessible; but, just before reaching the latter place, an extraordinary phenomenon occurs that affords a nearly perfect section of this series. The whole face of the cliff up to some joint or "back" has gradually slid down over the shale scar, and laid bare a continuous section on the foreshore.

Section shown by the Great Slip near Hummersea.

		Ft.	In.
Dogger band		0	7
Ironstone - 3 ft. 6 in. Dogger, shaly - 1 „ 0 „ Ironstone - 4 „ 3 „	Main Seam	8	9
Ferruginous shale		2	0

		Ft.	In.
Ironstone	0 ft. 3 in.		
Shale	0 „ 4 „		
Ironstone	0 „ 5 „		
Shale	0 „ 6 „		
Ironstone, very fossiliferous	0 „ 9 „		
Shale	0 „ 3 „		
Ironstone	1 „ 0 „		
} Pecten Seam		3	6
Shale		4	6
Ironstone, Two-Foot Seam		1	3
Shale		25	0
Ironstone, Avicula Seam		2	0
Shale, &c.			

The lowest beds are broken up and covered by sea-weed, so that details cannot be seen.

Immediately over Loftus Alum House there is a considerable cover of Drift, the Ironstone Series appearing again in Hummersea Cliff. There are several small exposures of shales and ironstone on the east side of Skinningrove Beck, about the Loftus Mine, the Two-Foot Seam being here 1 ft. 9 in. in thickness.

The base of the Main Seam and the beds below are cut through in Tan Head Wood, Cattersty Beck, and the following section was measured there :—

	Ft.	In.
Base of Main Seam.		
Ferruginous shale	1	6
Shale and ironstone, shelly, Pecten Seam	5	6
Shale	5	6
Ironstone, Two-Foot Seam	2	0

On both sides of Brotton Hill the Boulder Clay conceals all the lower ground, the Middle Lias being visible only in the cliff, but numerous borings and mining operations have proved the upper limit of the Ironstone Series. On the south side of Skelton Beck is a deep pre-glacial valley; the outcrop and extent of the Main Seam on both edges of it having been proved by a long drift, starting from the stream at the base of Hob Hill (see Fig. 4., p. 70). Recent workings in Longacres pit have shown the Main Seam to extend further north about Hagg Wood than indicated in the map; but it is attenuated, and much broken up, the base of the Upper Lias being as nearly as possible as drawn.

In Skelton Beck, just west of the viaduct, there is the following complete section of the whole of these beds, one, moreover, that is peculiarly accessible.

	Ft.	In.
Top dogger (Ironstone), not worked	2	4
Pyritous band, 0 to 3 inches	0	2
Ironstone, Main Seam	9	7
Very ferruginous shale, with doggers	2	5½
Shelly ironstone, Pecten Seam	1	9
Hard dark ferruginous shales	5	7
Ironstone, Two-Foot Band	2	5
Dark shale, with a thin band of ironstone	22	0
Ironstone, Avicula Seam	2	0
Shale, harder and more sandy (about)	25	0
Siliceous ironstone	0	10
Sandy shale, with *Am. margaritatus, &c.*	7	6

Below this comes the Sandy Series, the upper beds of which are extremely full of fossils.

The Ironstone Series forms an encircling ring round Hob Hill, but, on three sides, its boundaries are entirely obscured by Boulder Clay. Upleatham Hill is surrounded in a similar manner by the same beds, their upper limit being exposed on the north side in the old ironstone quarries, the section seen being as follows :—

	Ft.	In.
Dogger, an ironstone, pyritous and impure	2	4
Sulphur band (Iron Pyrites)	0	2
Ironstone, MAIN SEAM	9	0
Marbled-stone	0	7
Ferruginous shale (about)	2	0
Shelly-ironstone, PECTEN SEAM	1	5
Hard dark shale	5	0
Ironstone, TWO-FOOT BAND	2	2

Lower beds than this are not exposed about Upleatham Mines. It is worthy of note that a small thin band of finely laminated sandy shale occurs about two feet above the first bed here given, which, no doubt, belongs to the Middle Lias, but it is only obscurely seen in a few places.

On the west side of Upleatham Hill, mining operations have proved the upper boundary of the Ironstone Series beneath the Boulder Clay. To the east of Eston Hill a great number of borings have been put down to prove the extent of the Main Seam. Between the two hills is a considerable spread of the lower beds of the series, the highest bed with the ironstone being preserved only in the synclinal, about Dunsdale Mine.

On the north side of Eston Hill the strata rise in succession above the drift covering, but owing to the steepness of the hill, a considerable part of the Middle Lias is obscured by downwash. The trials for the Main Seam give a clear line for the top of the Ironstone Series.

About Court Green the following section may be seen:—

			Ft.	In.
Hard ironstone, impure ; used for a roof in mining			3	0
Band of Iron Pyrites, in oolitic grains			0	6
Main bed of blue oolitic ironstone, MAIN SEAM			11	0
Mottled shale and ironstone, in streaks	1 ft. 1 in.	PECTEN SEAM	2	10
Dogger (Ironstone) band	0 „ 4 „			
Masses of shells, *Pecten*, *Belemnites*, *Avicula*, &c.	0 „ 5 „			
Mottled shale and ironstone, shelly base	0 „ 5 „			
Shale and ironstone, shelly	0 „ 7 „			

This shelly base of the Main Seam, that is the Pecten Seam, varies much, but, on the whole, thickens as we approach Eston Hill, where it is little less than five feet thick. At the top of the middle incline, beds slightly lower are seen, consisting of ferruginous shales, seven feet, with the Two-Foot Band or Seam below. On the north side of the Eston outlier no beds are seen beneath the Two-Foot Seam, and on the south, the entire series is, for a considerable distance, cut out by the great Upsall Fault. Near Scugdale, however, the fault seems to split into two, and

the throw of the main fault is so much diminished that the Ironstone Series is seen resting against sandstone of the Lower Oolite. The numerous trials for the Main Seam in this neighbourhood, bring out this last fact very clearly. In the most easterly of these openings the following section is seen :—

	Ft.	In.
Base of Main Seam, looks like a red gravel		
Mottled shale, with streaks of ironstone	1	0
Shales, crumbles to small pieces	2	0
Shelly beds, with ironstone and shale partings, Pecten Seam	2	4
Ferruginous shale	5	8

From the above it will be seen that on the south side of Eston Hill the Pecten or Shelly Seam is not immediately under the Main Seam, as on the north side, but is separated by three feet of ferruginous shale, and cannot, in consequence, be mined with the latter seam, as is proved in Chaloner's Pit.

That part of outcrop of the Ironstone Series that passes south of Upleatham Hill gradually narrows towards Capon Wood, and about Skelton Ellers. Since the country was surveyed, mining operations at Park Pit have proved that the ironstone is of greater extent than shown on the map, continuing right under the stream. The outcrop is in consequence in the shape of two V's with their apices towards each other, thus ><, instead of two roughly parallel lines. As, however, the roof is of clay, the upper limit of the Ironstone Series is practically drawn correctly. The Boulder Clay is here so thick that no rock is seen along the valley.

At Tockett's Lythe, the solid rocks come once more to the surface, the hill being composed of the lower beds of the Series. The Main Seam is commonly believed to exist here, but such is not the case. A little south of Waterfall is an exposure of shale, with ironstone, while further up the stream and in the railway cutting, is a nearly complete section of the Ironstone Series. It is as follows, in descending order :—

		Ft.	In.
Ironstone, much quarried, Main Seam			
Shale, with thin streaks of ironstone			4 6
Ironstone and shale	1 ft. 2 in.		
Shelly ironstone	0 „ 9 „		
Ferruginous shale	0 „ 2 „	Pecten Seam	4 0
Ironstone, shaly and shelly, *Pecten, &c.*	1 „ 5 „		
Shelly ironstone	0 „ 6 „		
Crumbly shale			5 0
Ironstone, *Am. clevelandicus*, Two-Foot Seam			2 6
Light sandy shale			6 0
Sandy ironstone			0 3
Sandy shale			19 0
Hard ironstone, Avicula Seam			1 10
Sandy shale			5 0
Thin sandstone, *Pecten lunularis*			0 4
Hard sandy shales			6 0

The Ironstone Series may be easily followed in the lower part of the great hill, south of Guisborough. There are many small exposures, principally of the upper beds, the best of which occur

about Belman Bank. In the neighbourhood of the old Hutton Mines the workings have exposed several clear sections, from which the following has been compiled;—

	Ft.	In.
Ironstone, Main Seam	—	
Ferruginous shale, with thin streaks of ironstone	4	4
Ironstone with bands of *Pecten*, Pecten Seam	3	6
Green shales	2	8
Ironstone, hard, Two-Foot Seam	2	7
Green shale	6	6
Blue oolitic ironstone	1	0
Sandy shale, with finely laminated sandstone	20	0
Thin band of sandy ironstone	—	
Soft sandy shale	20	0
Hard sandy shale	10	0
Sandy shale, with ferruginous doggers containing many fossils	6	0

Further west and south the beds below form a bold flat-topped escarpment, in consequence of which there are no natural sections of the Ironstone Series, the few trials for the Main Seam being the only positive evidence. The shape of the ground, however, shows very clearly the position of the upper part of the Middle Lias. The great whin quarries near Ayton, expose the whole of the Lias from the Jet Rock to the beds containing *Am. capricornus* but owing to the calcination of the strata against the dyke, this is not a good place for their examination. The dyke runs just under Howl Road, above Bank House, but does not come quite to the surface, the trials for it having reached only the calcined ironstone. Circling round Easby Bank, on which Captain Cook's Monument stands, the upper beds are clearly seen just above Burrow Greens, but beyond this a quantity of detritus obscures the ground as far as the old Kildale Mines. The workings here have exposed the following section:—

			Ft.	In.
Lenticular hard shale and doggers			1	0
Hard shale			1	10
Indurated shale band			0	3
Sulphur band			0	2
Ironstone	2 ft. 3 in.	Main Seam	4	10
Shale	1 „ 1 „			
Ironstone	1 „ 6 „			
Ferruginous shale			3	8
Shelly ironstone, *Am. spinatus*, &c.	0 ft. 11 in.	Pecten Seam	2	6
Shale	0 „ 2 „			
Ironstone, *Pecten*, *Avicula*, &c., in masses	0 „ 2 „			
Shale	0 „ 3 „			
Ironstone, few fossils	0 „ 6 „			
Shale	0 „ 3 „			
Ironstone	0 „ 3 „			
Shale			2	2
Ironstone, Two-Foot Seam			2	5
Shale.				

This is the most south-westerly of the sections in this area, and from it we may note the rapid approach of the seams to one another. A little south of the area here described, the top part of the Main Seam splits up completely, and the base, the Pecten Seam, and the Two-Foot were worked together. It was supposed

that all the beds there worked belonged to the Main Seam, but the fossils proved the lowest ironstone, with *A. clevelandicus, &c.*, to be the Two-Foot Seam.

There is a small exposure of these beds at Salt Scar, the extreme north-east of the scars opposite Coatham, where sandy shales with ironstone nodules are seen dipping north at 2°. It is evident that the beds are about to change their dip here. Unfortunately, only the base of the Ironstone Series is seen, and none of the more important beds of ironstone are on.

From the foregoing sections we may draw the following conclusions as to the changes that the strata undergo. The series, as a whole, is thickest towards the east, but as the shale thickens, the ironstone diminishes, both in quality and thickness. Examining the beds in detail, the upper part of the Ironstone Series at Eston consists of the following parts :—

1. Top block, an impure ironstone, about three feet thick, used as a roof, and never mined at Eston. At the base of this is a band of iron pyrites with oolitic grains, which forms a well marked horizon.
2. Main Seam proper. A blue oolitic ironstone, of almost uniform character throughout. *Am. spinatus*, the large *Pecten æquivalvis, &c.*, which occur isolated. Thickness about 11 feet.
3. Black-hard, or mottled stone, a highly ferruginous shaly ironstone, full of shell masses. Of these the most common is the *Pecten æquivalvis*. In this bed, but not at Eston, we have also found *Am. spinatus*. In consequence of the profusion of the former fossil, we have called this the Pecten Seam, being, in fact, the bed worked at Grosmont.

This last shelly ironstone may be followed under Eston Hill in the main road that passes to Chaloner's Pit. But in its course, instead of being immediately under the Main Seam as at Eston, it is separated from the blue oolitic stone by a bed of shale three feet thick on the south side of the hill. Again, in the sections at Spa Wood and Kildale Mines, the shale parting is well seen, while it was proved in Lingdale Pit to be three feet thick. On the coast at Staithes Nab the bands of shelly ironstone, with the masses of *Pecten*, are very clearly seen, as indeed are all the ironstone beds. There are three feet six inches of shale immediately above the Pecten Seam here. In the Upleatham and Skelton district the bed can be instantly recognised, and the evidence from all these exposures conclusively shows that this bed at the base of the Main Seam, or as we call it the Pecten Seam at Eston, is identical with the Pecten Seam at Grosmont. The latter being no part whatever of the Main Seam proper, as worked at every mine except Eston.

Following the Main Seam proper, it is found to thin slowly in a line very slightly north of east starting from Eston. Before reaching the coast the central part of the seam undergoes considerably change, becoming at first yellow and hard to drill, this portion being known as the "dogger" or hard band in the seam. It is always inferior in quality to the rest of the bed. This "dogger," moreover, is afterwards divided by a band of shale, which, when thick, has to be picked out from the seam, considerably increasing the cost of working. Both under Eston and

Upleatham Hills there is a clean seam free from both the dogger band and shale. In the Skelton district the seam has no shale-parting north of a line drawn roughly from Waterfall Wood through Airy Hill just north of South Skelton Shaft, then on to Carlin How Shaft, where the shale is only just visible, and so to the sea at Rockcliff. A little south of this the shale comes on in the middle of the ironstone ; in fact replacing the ore, which rapidly thins and deteriorates.

As observed above the seam thins most slowly along a line drawn from about Upsall shaft in Eston mine, a little south of Upleatham village, then south of Brotton and on to the coast. North of this line the seam thins at first slowly, then more rapidly, as will be seen by comparing the sections, to be given presently, at the south and north end of Huntcliff mine. This is also noticeable in Upleatham mine, though not so clearly shown.

South of the line the ironstone generally becomes slowly thinner before the shale comes on ; but after that thins very rapidly. For example, the Main Seam is 11 feet thick in Upsall shaft, but at Hutton the seam consists of—

	Ft.	In.
Ironstone	2	9
Shale	1	5
Ironstone	1	3

or in other words, of only 4 ft. 0 in. of ironstone, and that of an inferior quality. The changes that take place are extremely regular, and if a section is required it may be calculated from the nearest known section by bearing in mind the above remarks. South of the "Shale Line" it is not in the least probable that the seam can be better at any point south or east of a pit at which it has been proved ; any statements to the contrary must be received with the greatest caution, borings not being always reliable.

The following sections of the Main Seam of Ironstone will be sufficient to afford an estimate of the ironstone in any part of the area here described.

In the Normanby Mine.

	Ft.	In.	Ft.	In.	
Main blue oolitic stone	6	10	8	2	Ironstone.
Shelly (Pecten) seam	1	4			

In the Eston Royalty, at Upsall Pit.

	Ft.	In.	Ft.	In.	
Main blue oolitic stone	11	0	15	6	Ironstone.
Shelly stone (Pecten)	4	6			

At Chaloner's Pit.

	Ft.	In.
Main Seam, blue oolitic stone	9	10

The shelly bed is not worked, and, in fact, is never taken with the Main Seam except at Eston.

Under Upleatham Hill at the North End.

	Ft.	In.
Ironstone	9	0

Under Upleatham Hill at the South End.

	Ft.	In.
Main Seam	9	6½

Hob Hill.

	Ft.	In.
Ironstone	9	7

Longacres Pit.

	Ft.	In.
Ironstone	8	6

North Skelton.

	Ft.	In.
Ironstone	9	6

Huntcliff Mine, North End.

	Ft.	In.
Ironstone	6	3

Huntcliff Mine, South End.

	Ft.	In.
Ironstone	8	3

Brotton Mine, North End.

	Ft.	In.
Ironstone	6	10

Brotton Mine, South End.

	Ft.	In.
Ironstone	8	6

Crag's Hall Mine, near the Shaft.

	Ft.	In.
Ironstone	8	9

Crag's Hall Mine, South End.

	Ft.	In.
Ironstone	4	3
Hard Ironstone	1	2
Ironstone	4	1

Skelton Park Pit.

	Ft.	In.
Ironstone	9	10

Spa Wood Mine.

	Ft.	In.
Ironstone	3	3½
Shale	0	5½
Hard Ironstone or dogger	0	9½
Ironstone	4	2½

Boosbeck Mine.

	Ft.	In.
Ironstone	3	6
Dogger	1	11
Ironstone	3	0

South Skelton, near the Shaft.

	Ft.	In.
Ironstone	3	5
Dogger	1	0½
Shale	0	1
Dogger	1	0
Ironstone	2	10

South Skelton, South end.

	Ft.	In.
Ironstone	3	9
Dogger	0	7
Shale	0	7
Dogger	1	4½
Ironstone	2	2½

Lingdale Mine, North end.

	Ft.	In.
Ironstone	4	1
Dogger	0	7
Shale	0	6
Dogger	1	5
Ironstone	1	8

Lingdale Mine, South end.

	Ft.	In.
Ironstone	4	0
Dogger	1	0
Shale	0	10
Ironstone	2	10

Kilton Mine.

	Ft.	In.
Ironstone	3	6
Dogger	0	8
Shale	1	7
Ironstone	2	4

Carlin How Mine.

	Ft.	In.
Ironstone	4	6
Dogger	0	4
Shale	0	2
Dogger	0	4
Ironstone	4	0

Loftus Mine.

	Ft.	In.
Ironstone	4	0
Dogger	1	8
Ironstone	4	0

Liverton Mine, North End.

	Ft.	In.
Ironstone	4	3
Dogger and shale	2	4
Ironstone	4	2

Liverton Mine, South End.

	Ft.	In.
Ironstone	4	4
Shale	1	3
Dogger	0	8
Ironstone	2	4

Boring near Handale Abbey.

	Ft.	In.
Ironstone	3	7
Shale	1	6
Ironstone	3	3

Grinkle Mine.

	Ft.	In.
Ironstone	3	5
Shale	1	4
Ironstone	2	5

The sections in the cliff and on the foreshore have already been given.

In the district south of Guisborough, the following sections have been measured.

South end of Stanghow Mine.

	Ft.	In.
Ironstone	3	1
Dogger	0	6
Shale	1	6
Ironstone	2	0

Weardale Iron Company's Mine, under Atkinson Wood.

	Ft.	In.
Ironstone	3	4
Dogger	1	9
Ironstone	2	3

Under Highcliff.

	Ft.	In.
Ironstone	2	4
Dogger (impure)	1	9
Ironstone	1	7

The Main Seam near Roseberry Topping consists of—

	Ft.	In.
Ironstone	2	9
Shale and Doggers	1	5
Ironstone	1	3

In Little Ayton Wood.

	Ft.	In.
Ironstone	2	8
Shale	1	0
Ironstone	1	4

In Kildale.

	Ft.	In.
Ironstone		
Shale	2	9
Ironstone	1	1
	1	6

Further east in Kildale.

	Ft.	In.
Ironstone		
Shale	2	5
Ironstone	1	4
	1	7

Shafts have been sunk in Lonsdale, South Leven valley, and also at Commondale; the details I have been unable to obtain. The seam at Commondale was said to be—

	Ft.	In.
Ironstone	2	0
Shale	2	0
Ironstone	2	0

the last being probably an over-estimate.

Above the Sulphur Band, which rests on the Main Seam at Eston, is a block of impure ironstone about three feet thick. This bed maintains much the same appearance in the Upleatham district, but south and east it is split up by thin shale bands, the latter increasing slowly till the section becomes practically shale with thin dogger bands, as shown at the Kettleness section on page 15.

Below the Shelly Bed or Pecten Seam is a stratum of shale which, at Eston, is 7 ft. 6 in. thick; below this again is the Two-Foot Seam, 2 ft. 1 in. in thickness.

The following are further details of the Two-Foot Seam :—

	Thickness. Ft.	In.	Depth below the Pecten Seam. Ft.	In.
Upleatham	2	2	5	0
Longacres	2	6	7	6
Lingdale	2	0	6	0
Spa Wood, near Guisborough	2	6	5	0
Hutton	2	7	2	8
Kildale	2	5	2	2
Grinkle	1	3	4	3
Staithes	1	9	2	7

On the coast, between Staithes and Huntcliff, this seam averages about 1 ft. 6 in.

Below the last seam, generally some 25 ft., is another bed of Ironstone that has been extensively mined at Grosmont, a little south-east of the area here described. This is known as the Avicula or Low Seam. About Eston its outcrop is concealed by detritus, and it is not known about Upleatham, although it undoubtedly exists in both places. Below Hob Hill it is well exposed in Skelton Beck, and is about 2 ft. thick.

At Spa Wood, near Guisborough, the thickness is 1 ft. 10 in.; but at Hutton it is only a few inches, unless the seam is entirely obscured by detritus. In the Kildale district there are no exposures at this horizon. On the coast the Avicula Seam is usually about 2 ft. thick.*

The table of comparative sections of the Cleveland Ironstone (on page 18) is intended to show, at a glance, the position and thickness of the various seams. Taking the Eston section as the standard, the Main Seam and Pecten Seam are in contact; but they soon separate, the latter at Hob Hill and Kettleness, forming a series of bands of shale and ironstone. This is the type of the Pecten Seam throughout the coast area. At Hawsker, but for the large *Pecten*, the position even of this seam would be unrecognisable. As there is no exposure near the coast about Whitby, the Grosmont section is inserted, forming a link to show the gradual dying away of the Main Seam. The peculiarity of the last section is the running together of the shaly ironstone bands to form a solid seam—the Pecten Seam. This still retains its shelly character as at Eston, and falls to pieces on exposure to the air. The Guisborough section shows the Main Seam, much thinned away, just before the shale band sets on in the middle. Further south it splits into two, as at Kettleness, and gradually approaches the type of Grosmont.

The Avicula or Low Seam is only worked at Grosmont, and, as the section shows, is not known so thick elsewhere. It may again be remarked that it used to be fancied, and, indeed, is still believed by many, that the Pecten and Avicula Seams of Grosmont are the Eston Main Seam split up by shale. A glance at this table shows the fallacy of the idea.

The Main Seam, in consequence of the enormous extent to which it has been mined, has yielded a great number of fossils, no less, according to Messrs. Tate and Blake, than 95 species. The following are confined, in this district, to the Main Seam :—†

Pitonillus turbinatus.	*Pleurotomaria rustica.*
Turbo bullatus.	*Cerithium liassicum.*
Arcomya arcacea.	*Ostrea sportella.*
„ *petræa.**	„ *submargaritacea.*
Mytilus aviothensis.	*Tancredia broliensis.**
Hinnites tumidus.	*Waldheimia resupinata.*
*Trigonia lingonensis.**	*Spiriferina signiensis.**
Pleurotomaria helicinoides.	*Rhynchonella acuta.*
Perna lugdunensis.	*Cidaris amalthei.**

Those marked thus (*), are not known to occur elsewhere in Britain. The most common species in the Main Seam are—

Ammonites spinatus.	*Pitonillus turbinatus.*
Belemnites breviformis.	*Cryptœnia consobrina.*
„ *paxillosus.*	*Ostrea submargaritacea.*

* For an estimate of the amount of ironstone in the Cleveland district, *see* "Proceedings of the Cleveland Institute of Engineers," session 1879–80.

† Tate and Blake, The Yorkshire Lias, p. 154.

Pholadomya ambigua.
Astarte striato-sulcata.
Waldheimia resupinata β.
Terebratula punctata.
Pecten æquivalvis.
„ *lunularis.*
Monotis cygnipes.
Macrodon liasinus.
Gresslya intermedia.
Pleuromya rostrata.
Arcomya arcacea.
Rhynchonella capitulata.
„ *tetrahedra.*
„ *lineata.*

Upper Lias.

The Upper Lias is essentially a thick bed of shale, chiefly argillaceous, and generally of a grey colour, getting nearly black in the lower part; its thickness is extremely constant, being 240 feet very nearly. It may be divided into three parts; first (and highest) the softer grey micaceous Alum Shale, with *Am. communis, Am exaratus* (*Am. elegans*, Sby.), *Am. bifrons*, &c., and *Leda ovum;* secondly, the hard dark shale with pyritous doggers, the characteristics forms being *Am. serpentinus* and *Inoceramus dubius;* lastly, the soft shale or Grey Shale, with the very restricted form *Am. annulatus.*

The following more detailed section was measured between Whitby and Saltwick, except the lower part, which is only seen in the cliff at Hawsker:—

	Ft.	In.
Shale, soft grey and micaceous, with cement doggers in the first 18 feet: *Am. communis, Am. bifrons, Leda ovum*, &c., abundant: *Myacites donaciformis, Nautilus striatus, Belemnites vulgaris*, &c.	34	0
Hard ferruginous shale band	0	4
Shale, soft grey and micaceous: fewer fossils	19	0
Lumpy calcareous band: *Leda ovum*, well preserved, *Lingula*, &c.	0	4
Shale, similar to above, but slightly harder at base	20	0
Band of hard shale	0	3
Shale, harder and darker; the beds above to the base of this are used for making alum (Alum Shale)	20	0
Double band of pyritous doggers with *A. ovatus.*		
Hard blue-black shale, with slight bituminous odour: large *Inoceramus dubius*	18	0
Hard black shale, similar to above, thin band of pyritous doggers at base	10	0
Hard black shale, bituminous; band of pyritous doggers, with casts of *Inoceramus dubius* (small) on the exterior	24	0
(This band is at the base of Saltwick Nab, and by the dip there, will be between the Nab and low-water mark.)		
Hard dark bitumous shale	30	0
Jet Rock, hard platy rock, with thick dogger at top; source of all the "Hard Jet"	25	0
Soft shale or Grey Shale	30	0
Total of Upper Lias	231	0

Owing to the Jet Rock being important as the source of a valuable mineral, it is mapped wherever possible; this course

being rendered more easy by the strongly marked lithological and palæontological characters of the bed.

The Grey Shale, or soft shale is the bed that rests immediately on the Ironstone Series; and consists, as its name implies, of a shale that weathers soft and grey. It contains bands of earthy impure ironstone, two of which occur close together about the middle of the bed, enclosing *Ammonites annulatus*, the characteristic fossil, in great abundance; *Belemnites cylindricus* occurs at about the same horizon. These two characteristic fossils are found occasionally in the lower part of the shale, accompanied by a few shells of Middle Lias type, apparently dwarfed. With these slight exceptions the Grey Shale is remarkable for the paucity of its fauna, especially when contrasted with the beds above and below. Owing to its forming a hollow, from its soft nature, sections in this part of the Upper Lias are rather rare, the only good ones being at Overdale, on the coast near Lythe; along the foreshore north of Goldsborough; on the south side of Runswick Bay; and in Brackenberry Wyke, near Old Nab. Small exposures above the openings into the Main Seam occur at Eston and Upleatham mines, but are not easily examined, from the steepness of the face. Although these soft shales do outcrop in a long line above the Ironstone Series, they form a hollow filled with debris from beds above, and, in consequence, are rarely seen.

The Jet Rock.—This division of the Upper Lias is in marked contrast to the bed below, being remarkable for its even bedding, splitting into long thin laminæ, and for the abundance of fossils in it. It is of a dark colour, and contains many rows of small round or oval pyritous doggers, usually covered with casts of *Am. serpentinus* and *Inoceramus dubius* on the outside; or containing them, generally well preserved, inside. In this latter case the Ammonite will often be found to contain liquid bitumen in the chambers. The nodules have only a pyritous skin or coat, the interior being a blue cement-stone having a powerful odour of mineral oil. At the top of the Jet Rock is a continuous band of doggers, which may be well seen at Saltwick, at low tides; they are sometimes as much as 15 feet in diameter, and very hard, being composed of sandy shale in long thin plates, cemented together by carbonate of lime and iron. This continuous dogger-band forms the roof to all the workings for Hard Jet,* as it occurs in greatest quantity for about 10 feet below this band.

The long line of breakers that can be seen at almost all tides from Black Nab to Saltwick is caused by the top of this rock, the lenticular doggers of calcareous and ferruginous shale, being here very hard and of enormous size. At very low tides the breakers caused by this bed can be clearly seen from the top of

* This jet appears to be formed of water-logged coniferous wood, from which in a few rare cases all trace of structure has been removed.

the cliffs in the form of a curve stretching west till it is due north of the Old Abbey.

In addition to the two fossils mentioned above, *Am. exaratus*, *Am. heterophyllus*, *Am. gracilis*, and *Belemnites tubularis* are tolerably abundant; a peculiarity of this bed being the great number of Cephalopoda as compared with other mollusca. Our knowledge of the fauna of this rock has, of course, been greatly increased by the jet-mining; remains of saurians and fish, particularly *Lepidotus semiserratus*, being frequently met with in consequence.

To the west of Whitby, the Jet Rock occupies the foreshore from Sandsend Ness to Overdale, and keeping in the foot of the cliff for a few yards, again forms the scar as far as Loop Wyke. The weird caverns in the foot of the cliff under Goldsborough are caused by mining the Jet. In this district many fine Ammonites may be obtained, as the ground has not yet been much hunted; but care must be taken not to be caught by the tide. This bed has been mined whenever it outcrops along the coast, and, owing to an improvement in the Jet trade, the workings have recommenced. From the shale brought out many scales of fishes may be found, of a soft blue tint, and occasionally the whole cast, about five to seven inches long. Owing to the quantity of bitumen and pyrites in this rock, spontaneous combustion is often set up, the effects of which are well seen near Old Nab.

The Jet Rock keeps a little above high water-mark along the east side of Runswick Bay, descending to the foreshore at Hob Hole. The next outcrop is at the north-west point of the Bay, this bed forming the foreshore in front of the ruined ironworks. A fault throws the strata down to the west, so that these shales form the greater part of Rosedale Wyke, their base being at about high-water mark half-way between the Wyke and Old Nab. From this point the excavations in the face of the cliff show the position of the Jet Rock as far as Staithes, where it turns inland, and is lost sight of under the Boulder Clay. A small exposure of it occurs in the small stream in Well Dale, just below Hinderwell village.

Jet has been extensively mined in the small dale in which is the entrance to Grinkle Mine, but beyond this, clay obscures the beds as far as the cliff face. With the exception of these last workings, the rock has not been mined along four miles of its outcrop, in consequence of the drift cover. In the cliff itself a small kind of step has been produced, by digging away the bed between the Boulby Alum Works and the west end of Loftus Alum Works. About Hummersea banks it has not been mined, though its position is clear enough, but on turning inland the outcrop again plunges under thick drift, and is not seen till Huntcliff is reached. Masses of the Jet Shale testify to extensive old workings, about the foot of Warsett Hill, but the southerly dip quickly takes the bed under Boulder Clay once more. Along the main line of outcrop there are no exposures for some six miles. At Spa Wood or Slape Wath, east of Guisborough, the workings recommence, and have been carried on at intervals in the face of

the great hill as far as Roseberry Topping. The so-called Ancient British Settlements here are nothing but pits sunk for the Jet. In former times pits were almost invariably sunk, levels being very rarely, if ever, resorted to.* The fact of pits being sunk, show the workings to be of great antiquity; as also we should infer from all record of them being lost. The apex of the great hill through which the dyke passes is formed of a small outlying patch of Jet Rock. To the south and east of Roseberry there are no Jet workings in the great escarpment, these being next seen on the west side of Easby Bank, and again on the south-east.

The Jet Rock when undecomposed is excessively hard and difficult to mine. It is usually covered by a steep bank of water-tight shale of great thickness. In consequence the bed is decomposed only for a short distance under the hill, the miners driving a short level till they reach the unweathered rock, which they call the face. Galleries turn off, right and left, from the main drift parallel to this face, and the jet is found in taking out the shale. Of course, it is quite a chance if any is found. In the outlier of Hob Hill the shale cover is so thin that the whole of the Jet Rock is more or less weathered, and the workings have gone a considerable distance under the hill, as may be inferred from the great tip-heaps. These latter took fire one summer, and burnt for a long time, causing a dreadful stench in Saltburn, more than a mile away. Along the north face of Upleatham and Eston Hills, the Jet workings are very extensive, but the other flanks of these hills are drift-covered, and the bed has not been mined in consequence.

The following fossils have been collected from the Jet Rock along the coast in the area here described :—

Inoceramus dubius, Sby.
Posidonomya Bronni, Voltz.
Ammonites cornucopia, Y. & B.
„ *elegans*, Y. & B. (? = *concavus*, Sby.)
„ *exaratus*, Y. & B. (? = *A. elegans*, Sby.)
„ *gracilis*, Simp.
Ammonites lythensis, Y. & B.
„ *ovatus*, Y. & B.
„ *semicelatus*, Simp.
„ *serpentinus*, Rein.
Aptychus.
Belemnites breviformis, Voltz.
„ *lævis*, Simp.
„ *Voltzii*, Phil.
Gyrosteus mirabilis, Ag.
Lepidotus semiserratus, Ag.

Alum Shale.†—The rest of the Upper Lias consists of soft grey Alum Shale, with harder and darker shales below. There is, in fact, a gradual change from the hard Jet Rock to the soft beds

* The old lead-workings in the West Riding prove this point conclusively.
† This includes more than the beds used for alum manufacture. The Jet Rock includes only the bed actually worked for jet.

that weather to a fine mud, quite at the top of the Lias. The upper beds contain much disseminated pyrites, in consequence of which they were formerly used for making Alum. They are characterised by the abundance of *Am. communis* and *Leda ovum*, *Am. bifrons* being also a common fossil. The harder beds, being more like the Jet Rock lithologically, approach it more in their fauna; Ammonites of the type of *Am. serpentinus* being most abundant; *Inoceramus dubius* and *Posidonomya Bronni* occurring quite at the base.

The most easterly and best known exposure of these beds occurs in the cliff and on the scars between Whitby and Hawsker; but so ransacked for fossils has this district been, that it is a bad place for collecting. After being depressed below sea-level by a great fault at Whitby Harbour, the Alum Shale rises again on the coast about a quarter of a mile before reaching East Row, where it is seen capped by the Dogger. It continues in the sloping hill for some distance, and is then covered by Boulder Clay, its outcrop in the steep bank on the south side of Mulgrave Woods not being seen. At Rock Head, however, is an old Alum Quarry, where the upper beds are well exposed, lower beds being seen in the sides of the small streams close by. Hell Sear, near Mulgrave Castle, is chiefly composed of Alum Shale, the capping of Oolites being very thin; from the base of this scar to the sea, the bed of the stream is composed of the hard shale below, a band of pyritous doggers with *Am. ovatus* keeping a few feet up in the bank all the way.

From Sandsend to Kettleness and Runswick Bay, the greater part of the cliff consists of these beds, but they are only accessible as a rule in the old Alum Works, such as Sandsend or Lythe, and the great Kettleness Alum Works. In the former, cement nodules in the upper part of the Alum Shale were still worked in 1877, a considerable number of fossils being occasionally found in some of these. This is worthy of notice, as these nodules have almost disappeared further west at Kettleness. A tunnel, moreover, has just been driven through part of the Upper Lias, and a great number of specimens ought to have been turned out if they were present in these beds.

At the Kettleness Alum Works, a few years back, Ammonites of the same group as *Am. communis*, might be found by hundreds, lying loose on the floor of the huge quarry. Its distance from any town caused it to be little visited, though it and the bay in which it occurs, are among the most picturesque objects on the English coast. The great point of interest in these Ammonites is the perfect series that can be found to show the gradual transition of *Am. communis* to the extreme type of *Am. crassus* on the one hand, and *Am. Holandrei* on the other. The Alum Shale has been denuded away in the centre of the bay, and its place taken by Boulder Clay, but it reappears in the cliffs at Runswick, and forms an encircling ring round the outlier of Hinderwell Fields The outcrop, however, is visible only in the cliffs.

No part of the great mass of Upper Lias shown on the map south of Hinderwell, is actually visible, the old valley in which it occurs being completely filled with drift, and it is not till reaching Rousby Beck under Low House, where there is a fine scar, showing the upper part of the Lias and its junction with the Oolite, that the Alum Shale is once more seen.

The next exposure of importance is in the cliff at the Boulby and Loftus Alum Works. When we see these colossal quarries, all of which have been dug out to make Alum, it becomes apparent why huge saurians have been so often found in the Upper Lias of Yorkshire; it is of course, owing to the countless tons of it that have been dug out. At Boulby House, one of the gravel walks is bounded by saurian vertebræ found in the Alum Works close by. Some fine specimens of *Leda ovum* may be obtained here from a band of red ferruginous shale.

After passing the Loftus Alum Works, little or nothing is seen of the Alum Shale for a considerable distance, except the small exposure near the Liverton Mines. The rabbits have turned out small fragments of the shale on the north face of Warsett Hill, but on the other two sides, the bank alone shows by its shape the position of these beds. The Hagg Alum Quarry near Saltburn, gives an interesting section, as it shows the complete absence of the bands of cement nodules, and also the scarcity of fossils in this part of the area. Along the main outcrop, the next good sections are reached at Spa Wood or Slape Wath; the intervening ground being practically concealed by drift. Rock Hole, Spa Wood, Cass Rock Quarry, and Belman Bank Quarry, are all old Alum Works in the immediate neighbourhood of Guisborough. In all of them the comparative absence of fossils may be noted. The Alum Shale being completely free of drift in this district may be easily followed round the great escarpment south of Guisborough, but clear sections are rare. These beds are better seen round the outlier on which Captain Cook's Monument stands, the old Alum Works, just north of Hunter's Scar, giving a clear section of the upper part. The long narrow strip of Upper Lias in Sleddale, is exposed in the banks of the stream in several places, some of which can be conveniently examined. In Kildale the calcined shale is seen against the sides of the dyke. The small portion of Upper Lias above the Jet Rock at Hob Hill, is quite concealed by drift. In Upleatham Hill, the north side alone is clear of drift, and even this cannot be examined, owing to vegetation and detritus. On the north of Eston Hill a similar state of things is seen, except that a few trials for the Dogger, above the Alum Shale, have exposed the upper part of the latter beds. The outcrop on the east side of this great outlier is completely covered by drift or detritus, and on the south side the great fault has entirely cut out the Alum Shale, except quite at the south-east corner of the hill.

The following fossils have been collected from the Alum Shale :—

Discina reflexa, Sby.
Lingula longovicensis, Terq.
Avicula inæquivalvis, Sby.
„ *substriata*, Münst.
„ sp.
Gresslya abducta, Phil.
„ *donaciformis*, Phil.
Pecten sp.
Inoceramus cinctus, Münst.
Leda ovum, Sby.
Pleuromya contracta, Simp.
Trigonia literata, Y. & B.
Venus tenuis, K. & D

Ammonites bifrons, Brug.
„ *communis*, Sby.
„ *crassus*, Y. & B.
„ *Desplacei*, D'Orb.
„ *exaratus*, Y. & B. (? = *elegans*, Sby.)
„ *heterophyllus*, Sby.
„ *Holandrei*, D'Orb.
„ *lythensis*, Y. & B.
„ *radians* (?) Rein.
Belemnites lævis, Simp.
„ *levideusis*, Simp.
„ *Voltzii*, Phil.
„ *vulgaris*, Y. & B.

CHAPTER IV.

OOLITES.

Lower Oolite.

The Dogger.—Overlying the Upper Lias is a bed of very variable character, known as the Dogger, or Top Bed. It consists of sand bound together by the carbonates of iron and lime. As each of these three constituents predominates, the Top Bed is a ferruginous and slightly calcareous sandstone, an ironstone, or very rarely a bastard limestone.

This first character prevails generally over the eastern part of the district, the second in the centre where seen in the coast section; and the third at rare intervals, and then only covering a small area. This last phase is, however, very well shown just south-west of the area here described.

In the extreme west, under Eston and Upleatham Hills, there are ironstone nodules in shale above the Upper Lias, which probably represents the Dogger, but in the absence of any fossils it is not easy to prove this.

In describing the very complete section at Blea Wyke, several authors have debated how much of the beds there seen belong to the Upper Lias, and how much to the Lower Oolite. But the Dogger in the area now described, summarily disposes of that question by showing such fossils as *Lingula Beanii* side by side with fossils from the highest part of the Blea Wyke section. This proves conclusively, that the line adopted by Messrs. Tate and Blake in their "Yorkshire Lias," and also by the Survey is the correct one; if any part of the Blea Wyke Beds are Oolitic, all must be.

At the extreme south-east corner of Sheet 104, the Dogger is about 10 feet up in the face of the cliff, and the following section is seen:—

		Ft.	In.
Sandstone		20	0
Dark shales and thin sandstone		20	0
Coal		0	4
Sandstone (carbonaceous root-marks)		3	0
Dogger	Ferruginous sandstone	3	0
	,, ,, with pebbles	3	0
	Nodular band	0	8
Alum Shale.			

The coal seam is continuous for only a short distance further north, but can be followed for a considerable way to the south. The Dogger itself has the upper part full of casts of vertical *Equisetites*, but contains very few other fossils.

The section remains the same as far as the lighthouses, where a thick mass of false-bedded sandstone descends and cuts out the Dogger for a few yards.

In Saltwick Bay this bed is 2 feet 6 ins. in thickness, very hard, and with less silica than usual. At the base there are many

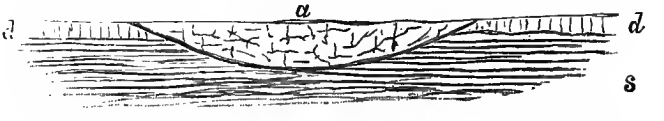
of the so-called pebbles. Some of these are waterworn fragments of *Belemnites* and *Ammonites*, the latter being unmistakably Lower Lias forms. This leads to the question, are not the little nodules or concretions also waterworn nodules from the Lias; it seems more than probable that they are, in which case "pebbles" is a perfectly correct word to use for them, though exception has been taken to the use of that term.

Approaching Whitby, the Dogger becomes still more ferruginous, nodules of ironstone appearing above the main part of the bed; still it is of no commercial value as an ironstone, being far too siliceous.

Just before reaching Whitby, the phenomenon seen under the lighthouse is repeated. After the Lias and the Dogger were deposited, a small local current has eroded a hollow through the latter, and a few feet down into the former. Sand has afterwards filled up the hole thus formed.

Fig. 2.

Local Erosion of the Dogger and the Upper Lias.



a. Estuarine Sandstone. *dd*. Dogger. *s*. Alum Shale.

From this point the Dogger rises in the cliff till it is about 40 feet up near the East Pier; turning south, it descends rapidly to the river bed inside the harbour.

A large fault that runs through the harbour throws the Dogger down below sea-level, and it is not seen again till it outcrops a little way up Raithwaite Gill. Here the bed was formerly worked on a small scale by an adit; but the Boulder Clay has now slid over it, and entirely obscured the ground. Proceeding westward the south bank of the high road shows the following section :—

	Ft.	In.
Sandy calcareous ironstone with ferruginous joints	2	6
Calcareous and ferruginous sandstone, many pebbles	1	6
Concretionary, ferruginous sandstone, Pebble bed	2	0
Ferruginous, pebbly sandstone, Pebble bed	0	10
Ferruginous calcareous sandstone	3	2
Very hard nodular ironstone	1	2
	11	2

Red ferruginous shale, passing into Alum Shale.

The part of the bed worked appears to have been the last nodular ironstone band, which was thicker in some places; but its unreliability, both as regards quality and thickness, caused it to be abandoned some years ago.

For a short distance the Dogger continues in the cliff face, it then plunges under the Boulder Clay, and is completely obscured

for about a mile and a half, till it reappears in the bed of the little stream east of Trucky Rock Hole. Another and better exposure is seen in the stream that has cut out the latter place. Here the Dogger consists of two beds, each very hard and solid, weathering into rounded blocks with ferruginous casings. The upper bed is a red ferruginous sandstone, the lower of a much lighter colour, and more calcareous. In it may be found many fossils, though, as a rule, only a few species, such as *Terebratula trilineata, Pholadomya Sœmanni, Trigonia, &c.*

A very clear section is seen again in Rock Hole, just north of Rock Head, and in Biggersdale Hole, where a fair number of fossils may be collected.

The top only is seen in the bed of the two streams that flow through Mulgrave Woods, and the ground north of the old castle is much obscured by drift. The Dogger caps the Alum Shale at Hell Scar, due south of Mulgrave Castle, and from this place the outcrop is sufficiently clear as far as the Lythe Road, where a small tongue of clay obscures its course just before appearing in the Lythe Alum Works.

Here is, perhaps, the most accessible of all the sections of this bed. The following details were measured at the south end of the great quarry:—

	Ft.	In.
Ferruginous jointed concretionary sandstone	2	6
Ferruginous shale	0	10
Dogger band	1	0
Ferruginous shaly sandstone, pebbles	1	8
Ferruginous sandstone, weathering into large blocks	4	6
	10	6

The lower part of the last bed contains many pebbles and fossils, the latter chiefly in nests. *Terebratula trilineata* occurs in vast numbers; the less common fossils being *Lingula, Vermetus,* &c., all occurring as casts, and not easily determinable.

For some distance to the north, the Dogger becomes thicker, and less ferruginous; in fact, a sandstone, having a slightly oolitic appearance. There are ferruginous nodules at the top and base, and "pebbles" throughout.

Just north of Overdale, the cliff presents the following section:—

	Ft.	In.
Massive false-bedded sandstone	40	0
Shale, carbonaceous, with soft jet	50	0
Sandstone	5	0
Carbonaceous shales	1	6
Ferruginous shale	1	0
Slightly ferruginous sandstone, pebbles	8	0
Shale, with two rows of ironstone, nodules	4	0

Further north, though visible in the cliff, this bed is quite inaccessible till reaching Kettleness Alum Works. The section differs little from that last given, except that there is more ferruginous matter. This character becomes so much more marked a little

to the west, that a trial-hole was driven into the Dogger just against the small stream (Cat Beck) that passes by Kettleness village, and the following section was proved:—

	Ft.	In.
Typical "dogger," very ferruginous sandstone, pebble bed	4	0
Shale, ferruginous	1	6
Ironstone, of good quality	0	5
*Ferruginous sandstone, with pebble beds	4	0
Ironstone, with jet fragments	1	2
*Ferruginous sandstone	2	6
Shale	0	11
Ironstone, full of pebbles	0	5
Ironstone, hard, and of good quality	0	8
Total	15	7

After keeping in the face of the cliff, the outcrop turns inland along the east side of the small stream, below Claymoor, presenting much the same character. It then turns north, seaward again, and a trial-hole has been driven into it close by the old limekiln, about the centre of the bay. Though highly ferruginous, it is far too siliceous to be considered an ironstone. The old valley, through which the present Staithes Beck used to flow, is completely filled by Glacial deposits, and nothing is seen of the Dogger along its flanks on either side.

North-west of Runswick Bay is an outlier of Lower Oolites, with the Dogger at the base. Over the whole of this area the bed is more than usually ferruginous, and has been extensively mined; its outcrop, however, can be seen only in the face of the cliff. The following section was measured just north of Runswick:—

	Ft.	In.
Ironstone, hard and compact	0	4
Sandstone, ferruginous	1	0
Ironstone, very hard	0	7
Ferruginous, oolitic, concretionary sandstone	1	6
Ironstone	0	2
Sandstone, ferruginous	1	0
Sandstone, with ironstone nodules	4	0
Total	8	7
Alum Shale.		

From this point it rapidly becomes more ferruginous and less siliceous, in fact, an ironstone; the following section is seen at an old adit in the cliff face at Rosedale Wyke (now better known as Port Mulgrave):—†

	Ft.	In.
Hard stone (good quality)	1	0
Ferruginous marl	2	3
Hard stone	0	3
Pebble-bed	0	2
Grey stone	0	3
	3	11

* This might sometimes be called a siliceous ironstone; it is very variable.
† "Proc. Cleveland Institute of Engineers." 31 May 1880.

In working, this bed was found to vary between two and four feet in thickness. Towards the south side of the Oolitic outlier, near Hinderwell, the bed is cut out entirely by what the miners term a "freestone baulk," which is simply the repetition, on a larger scale, of the phenomenon described as seen near Whitby.

The exact position of the Dogger now becomes very uncertain over a large portion of its outcrop, for south of Hinderwell the Boulder Clay hides every trace of it, and there is no section within some 50 feet of it, in Borrowby Dale. The drift, however, becomes thinner along the face of Rousby Hill, and the outcrop is seen again in a little gully that opens into Rousby Beck, just under the Keeper's Lodge.* Here the section is :—

	Ft.	In.
Impure ironstone	5	0
Shale	2	0
Ironstone dogger (fossils)	0	6
Shale	1	0
Dogger band	0	6
	9	0

Alum shale, of a light colour, below.

About 100 yards further south the following section was measured, giving a fair idea of the rapidity with which the Dogger changes :—

	Ft.	In.
Sandstone	20	0
Sandy ironstone, with nests of shells	3	0
Shale	3	6
Dogger band	0	3
Shale	1	0
Dogger band	0	3

Alum Shale.

The outcrop can be followed into the bed of the stream, after which it passes under the Boulder Clay of Rigg Lane, and reappears on the west side of Easington Beck, but only part of the bed is seen here. The new Redcar and Whitby railway runs alongside the west bank of Easington Beck, and the small cutting shows the nature and thickness of this bed. It is an impure Ironstone, about three feet thick, more siliceous than further north. The few fossils in it are, for the most part, comminuted and unrecognisable.

Further north the outcrop is covered by Drift till the cliff is reached at the Boulby Alum Works. Here several instances occur of the denudation of part of the Dogger, the eroded hollow being filled with Estuarine Sandstone. In its normal condition the section is :—

	Ft.	In.
Hard oolitic ironstone	1	1
Softer stone, shelly	2	0
Ferruginous shale	0	6
Sandy ironstone dogger	0	4

* Low House on the One-Inch Map.

The first band is a good ironstone, while the second varies much, sometimes being of fair quality, at others very impure. The whole is essentially an ironstone here, but its quality deteriorates somewhat going further west.

The section in Loftus Alum Works is:—

	Ft.	In.
Massive sandstone	40	0
Carbonaceous shale	10	0
False-bedded sandstone	15	0
Ferruginous shale	12	0

		Ft.	In.		
Dogger	Pebble band on ironstone	0	6	4	6
	Hard shale and ironstone bands	3	6		
	Impure ironstone bands*	0	6		
Alum Shale.					

From the bed marked (*) Messrs. Tate and Blake record the following fossils:—†

Actæon Sedgvici.
Actæonina mitræformis, Braun.
Dentalium entaloides, Desh.
Ostrea flabelloides.
Lima toarcensis.
Pecten lens.
Mytilus imbricatus.
,, *cuneatus.*
Perna isognomoides, Stahl.
Leda rostralis, Lam.
Cucullæa cancellata.
Quenstedtia oblita.
Alethopteris polypodioides, Lindl. ? fragments of pinnules with sori.

Also species of *Belemnites*, *Anomia*, *Plicatula*, *Corbula*, Entomostraca, *Serpula*, *Pentacrinus*, *&c.*

After leaving the Alum Works, the base line of the Oolites recedes inland from the cliff, and owing to the thick downwash is not actually seen for a considerable distance, though its position is clear enough. In Deepdale the Dogger passes round an old Drift-filled valley, and its exact position is very uncertain. The presence of the valley was proved by the new engine-road down into Whitecliff Mine, which was cut for a considerable distance in Glacial deposits.

The Dogger crops out again in Whitecliff Beck, the small stream that flows from Loftus to join Skinningrove Beck, the section being—

	Ft.	In.
Very dense ironstone, slightly oolitic. *Terebratula punctata, Rhynchonella cynocephala (?) &c.*	0	10
Ironstone, softer and more oolitic	0	6
Ferruginous sandy bed, almost a sandstone	1	2
Hard ironstone, small fossils in lines or layers	0	9
Marly ironstone, a mass of fossils	1	6
Shaly calcareous ironstone, with the characteristic pebbles	0	6

From the last two beds fragments of *Ammonites* and *Belemnites* are occasionally found, but other fossils are extremely abundant, such as *Thecosmilia gregaria, Terebratula trilineata, T. punctata, Rhynchonella cynocephala, R. tetrahedra, Ceromya bajociana Pecten, Avicula,* &c.

† The Yorkshire Lias, p. 26.

There is a level from Liverton shaft through this bed to the day, and the ironstone brought out has yielded a great number of fossils.

To the south and west the outcrop is obscured by drift, and though its position can be fixed with tolerable accuracy, it is not seen again till Warsett Hill, overlooking Huntcliff, is reached. The Dogger here makes a small crescent-shaped spread; the Ironstone and ferruginous marl being quite bare even of vegetation in one or two places. It is evidently much the same as at the outcrop last described, but perhaps a trifle thicker. Just south-west of Warsett Farm, a well was sunk 48 feet to the Dogger, fragments of which can still be seen.

Going south along the side of the hill, the outcrop of the Top Bed is clear enough as far as Brotton Pit; afterwards it again crosses a line of old valley, and is lost sight of, but reappears in the alum quarry called Hagg Hole.

Here the section is as follows :—

	Ft.	In.
Carbonaceous shale	5	0
Shale, with thin streaks of ironstone	5	0
Ironstone nodules	0	2
Shale	2	0
Ironstone	0	1
Shale	0	4
Ironstone	0	3
Shale	0	7
Ironstone	0	3
Earthy ironstone, nodules, with *Belemnites*	0	6

Alum Shale.

This section is typical of the representative of the Dogger or Top Bed over a considerable district to the south and west; both in Eston and Upleatham Hills for example, and also in the face of the Guisborough escarpment. Indeed, it is doubtful whether there is any Dogger really present in some cases; but its absence is simply due either to non-deposition, or to the ferruginous nodules containing no distinctive fossils, and is not owing to its having been denuded away before the deposition of the Estuarine series, as is seen on the coast near Whitby.

In North Skelton and Skelton Park Pits, the Top Bed is given as "Ironstone nodules in shale"; and the sections in the old Alum Quarries about Guisbrough show 10 feet of ferruginous shale with ironstone nodules immediately above the Alum Shale. A similar feature is seen both in the Upleatham and Eston Hills, the pits in the latter passing through from 5 to 12 feet of "shale with ironstone nodules."

It is not till passing completely round the district of Great Ayton Moor and Captain Cook's Monument that the Dogger again becomes a distinctly recognizable bed. At the junction of South Leven Valley and Kildale, a series of drifts have been made into the Top Bed. It here consists of a band of ironstone, hard, and of good quality, about 10 inches thick, containing *Pholadomya Heraultii* in great numbers. This rests upon five

feet of ferruginous marly stone, very shelly, and containing many "pebbles." A similar, but thinner section is seen just over the old dam that the railway crosses in Kildale. A boring was put down in Lockwood Beck, and the Top Bed is given as "Ironstone 7 ft. 4 in.;" another, about the centre of the area here described, known as the Girrick Bore Hole, gives "Ironstone 7 feet;" but the quality in each case is not known. It is extremely unlikely that the stone is of any value as an ore.

Estuarine Series.—The Dogger is succeeded by a series of shales and sandstones of freshwater or estuarine origin. This series, known as the Estuarine Series, is divided into three parts by two marine or brackish-water beds, the Eller Beck Bed,* and the Grey Limestone Series. As the former of these is often either absent or untraceable, it will be described first; the estuarine beds, above and below it, being described together.

The Eller Beck Bed in this district is about 100 feet above the Dogger, and consists of thin fissile sandstone, with ferruginous shale below. The Shale contains ferruginous nodules in which small fossils are found. This is the section as seen at the top of the cliff on the east side of the Esk at Whitby, close by the Church Steps. From this point it can be followed, though quite inaccessible as far as Saltwick, where it turns inland, and is lost sight of under the Drift. To the west of Whitby the first clear exposure is near Kettleness in Cat Beck. Here the section is—

	Ft.	In.
Flaggy sandstone	4	0
Shale	7	0
Ironstone	0	6
Shale	1	0
Ironstone (impure)	1	0

Gryphæa, sp., *Astarte minima*, *Nucula minima*, and a *Littorina* are common at the base of the first ironstone band.

From this point the bed can be followed east and west as shown on the map.

Due east of Hinderwell in the face of the cliff a somewhat similar section is seen, the ironstone bands being much thinner. With this exception, there is no place between Lythe and Saltburn where beds so high as the Eller Beck are seen in the cliff.

Inland it has been recognised in the little stream close by Loftus Station. Here a small quarry shows about 15 feet of rather hard evenly-bedded sandstone. Below this is two feet of shale with ferruginous nodules at the base, containing casts of a small *Gryphæa*. This bed is succeeded by a thick sandstone. A similar section is seen in the banks of the next small stream to the east, where crossed by the railway. In an old quarry east of Brotton, and in another just south-west of the village are seen the fissile sandstone and shale resting on the thick sandstone, as above.

Under Mill Holme, near the Brotton and Skelton road, this bed has a very clear outcrop, though it presents no features of

* *See* Geol. Mag., Dec. II., vol. iv., p. 552, 1877.

interest. It is also seen in a quarry close by the road at Boosbeck, but further south and east it is not known in this district, neither have we been able to recognise it on Eston or Upleatham Hills.

A good general idea of the nature and thickness of the Estuarine Beds below the Grey Limestone may be formed from a detailed section, showing the alternations of sandstone, shale, &c.

In the year 1821, Col. Wilson caused a boring to be put down in a field just south of the Esk, and opposite the village of Ruswarp.

The section proved was as follows :—*

	Ft.	In.
Soil and gravelly clay (alluvium)	22	0
Blue metal (sandy shale)	10	0
Black Stone (bituminous shale)	2	0
Grey metal (grey shale)	3	0
Brown post (brown sandstone)	1	0
Grey metal	1	0
Yellow gullety stone (soft sandstone)	10	0
Grey metal stone with post girdles (hard nodules)	8	0
Yellow post (yellow sandstone)	6	0
Blue metal	15	0
Coal	0	4
Blue metal with skares of coal (bituminous shales)	11	8
Yellow skamy post	2	0
Blue metal	2	6
Black stone with a mixture of coal	0	6
Blue metal	3	6
Coal	0	6
Grey post with water	3	4
Whin (ironstone)	0	8
Grey post	3	0
Blue metal	8	0
Blue metal stone (blue schistose sandstone)	3	0
Grey metal	3	0
Grey and white post	7	0
Grey metal with post girdles	13	8
Blue metal stone	2	0
White post with metal partings	18	4
Grey metal with skares of coal	3	0
Grey metal stone	4	0
Whin	1	6
Grey metal with metal partings	10	6
Whin	1	0
Grey post with metal partings	18	0
Grey metal	2	0
Foul coal	0	5
Grey metal with post girdles	11	7
Grey post	3	0
Grey metal stone	14	0
Coal	0	4
Grey metal	4	2
Coal	0	11
Grey metal	6	0
Grey post	4	7
Whin (this and the preceding rock appear to form the "Dogger")	1	6
	247	6

* Young and Bird, "Geological Survey of the Yorkshire Coast." 2nd Edition, p. 124.

The boring was carried on nearly 100 feet further into the Alum Shale below. As it commences some 30 feet below the base of the Grey Limestone, which can be distinctly traced in the field above, the total thickness of the Estuarine Series below that bed is about 270 feet. Now in the cliff at the extreme south-east of the area here described, the Grey Limestone comes a few feet below the 300 contour line, just on the top of the cliff, or we may say, the base occurs at 300 feet, making a small allowance for the dip inland: as there is 12 feet of Alum Shale and about 3 feet of the Dogger, making 15 feet to be deducted, the thickness of Estuarine beds in the cliffs is 285 feet. The two coal seams proved in the boring just above the Dogger are also seen here, though they die away before reaching Whitby.* Proceeding towards this town, one cannot but be struck by the rapidity with which the strata change, thick beds of sandstone coming on in wedges, and often cutting out shale beds that were previously deposited. These wedges evidently represent the effect of local currents denuding hollows in regular deposits almost horizontal; an effect that we should expect to be produced by floods. That this is the cause of the sandstone wedges is supported by the fact of the large number of plants, principally ferns, that are to be met with in them, a feature well seen where the Dogger comes down on to the scars, near Whitby. It is also noteworthy that most of the soft jet, which is fossilised wood, occurs in considerable quantity in masses of rock peculiarly false-bedded and wedge-shaped. This was observed in digging away the rock at the east side of the cutting made to ascend the West Cliff from the pier at Whitby, when a considerable quantity of soft jet was met with. This jet here occurs at the same horizon as at Hawsker, that is, some 50 feet, or rather more, below the Grey Limestone Series.

Some distance to the west of Whitby in Raithwaite Gill fine sections of the sandstone and shales of the Estuarine Series may be seen, which are very picturesque, but not of much interest geologically. From this point to Warsett Hill, near Saltburn, all the higher points in the cliff are capped with Estuarine Sandstone and Shales, but only in one place do strata so high as the Eller Beck Bed come on. In the clear and easily-accessible cliffs north-east of Goldsborough the sandstones and shales can be readily examined; several of the shales here being good fireclays, though no coal is seen.

Inland there are good exposures in the various streams south and west of Mulgrave Woods. At the head of Borrowby Dale, and again a little north of Scaling, a thick bed of sandstone occurs close under the Grey Limestone, forming in the latter case bold and picturesque scars, while beds considerably lower in the series can be seen by following down Rousby Beck and Easington Beck. Liverton and Hagg Becks, which unite to form Kilton Beck, give a remarkably fine series of sections of the strata between the

* These strata are very much thicker nearer the Peak.

Eller Beck Bed and the Grey Limestone Series, forming the most beautiful stream scenery in the district; here again a thick mass of sandstone occurs close beneath the latter bed. A complete section from the Dogger to the Eller Beck Bed and some distance above is seen just south of Loftus, and again in the beck between Hagg Hole and Mill Holme.

Except the sandstones seen in quarries, there are no good sections about either Eston or Upleatham hills, but borings in the former have given a complete section of these beds. In the great escarpment south of Guisborough the old Alum quarries have exposed the lower strata very well, and bring out strongly the rapid changes in the Estuarine Series. At Belman Bank Quarry the basement beds are for the most part shaly, while about Highcliff an imposing mass of sandstone marks the junction of the Lias and Oolite.

In Commondale one of the fireclay beds is worked for making drain pipes of large size, and a superior class of perforated bricks. There is a nearly complete section in this neighbourhood, but we were unable to identify the Eller Beck Bed.

About two miles due east of Commondale is a series of old coal pits, sunk to a small seam about 50 feet below the base of the Grey Limestone Series. The seam is usually about 1 foot 3 inches thick, 4 inches of shale occurring about the middle of it. One of these pits is still * being worked on top of the hill north-east of Danby Station. They were commenced close by the outcrop below Doubting Castle. The seam has been followed as it rises in the hill, the water draining behind as the work advanced.

The present pit is about 120 feet deep, and pierces the Moor Grit, the Grey Limestone, and about 50 feet, or rather more, of Estuarine beds below. The coal is of poor quality, and smoulders rather than burns; it is in consequence principally used for lime-burning.

A deep boring was put down on Girrick Moor; but the coal was not found, neither was it in Dodd's borehole at Girrick further north, and it is not mentioned in Lingdale Pit.

In removing the bearing from a quarry on the hillside above Margrove Park, the seam is exposed, a very unusual thing. A small boring also proved it, close by Jenny Frisk Well on Low Moor, and it has been grubbed out at the outcrop close by Groundhills Head. A few small workings may still be seen close by North Skelton, but it must have been thin, or the workings would be more extensive. Borings put down by Messrs. Bell Brothers proved its extension under the upper part of Skelton Park Hill. On the other hand, there is no mention of it in North Skelton Pit; though too much reliance must not be put on this, as the account of the strata was not carefully kept. In Kilton Pit two seams, one six inches and another five inches are recorded, but, from the depth below the Grey Limestone Series, it is doubtful

* 1880.

if the upper one represents the Danby Seam. Two borings in the Easington district passed through the Moor Grit to the Ironstone, but apparently without meeting any coal seam.

In mining, the seam is often found to be cut out by a bed or wedge of sandstone, and it is probable that it once covered the whole of this district, but has since been denuded away in places previous to the deposition of the higher beds.

Grey Limestone Series.—This forms the most important marine bed in this group of rocks, and by its outcrop gives a key to the structure of the higher parts of the district; it being quite impossible, partly from the thick covering of Boulder Clay, but chiefly owing to their impersistent character, to follow the outcrop of the various beds between this horizon and the Dogger. The Series consists of three distinct sub-divisions. The upper part is composed of shale, containing ferruginous nodules, and is more or less calcareous towards the base; below this is a siliceous bed, which is a sandy marl in the eastern part, and a hard grit in the west; while at the base is a varying thickness of impure limestone bands.

By its outcrop the Grey Limestone marks three distinct areas; first, the country round Whitby, second, the main portion of the table land; and lastly, the isolated outliers of Skelton Hill and Eston. Near Whitby there are several exposures. Quite at the south-east end of the outcrop, as shown on the One-inch Map, the basement calcareous beds are seen, but to the north-west their position can be only inferred from that of the hard white Moor Grit above. This is the only evidence till Moorgate Lathes is reached, about a mile from the old church at Whitby, and a few hundred yards west of the high road. Here, in the bed of the stream, the upper part of the hard calcareous bands may be seen, with calcareous shales above. The section, however, is short, being soon hidden by drift. The Moor Grit crops out further up the stream, the lower part of it being a flaggy sandstone. About 200 yards south-west of this point, in the main branch of Spital Beck, is a waterfall that gives a complete section from the top of the Moor Grit to a considerable distance below the Grey Limestone. The beds, which can be measured in detail, are as follows:—

	Ft.	In.
Close grained sandstone, evenly bedded and flaggy at base	20	0
Softer flaggy sandstone, with casts of a *Myacites*	6	0
Band of ironstone nodules, small specimens of *Avicula braamburiensis*	0	4
Soft sandstone, splitting to very thin layers	3	0
Ferruginous sandy shale, slightly calcareous in lower part, with calcareous nodular band at base	3	0
Shaly limestone or marl, a mass of shells, *Avicula braamburiensis, Gervillia acuta, Pecten lens,* &c.	3	0
Hard blue siliceous limestone	1	6
Calcareous shale	5	0
Shaly limestone or marl	1	10
Hard sandy calcareous shale	4	0
Impure limestone band	2	0

Below this are dark shales with several trial-holes for soft jet, all of which appear to have been unsuccessful.

The shaly limestone bands are more of the nature of a fossiliferous mudstone with great numbers of *Aviculæ*, which, when first exposed, is very hard and difficult to break, but rapidly disintegrates from loss of lime, and can then be broken to pieces with the fingers.

From this point the outcrop under the Drift soon comes against the Whitby fault, and is thrown down to the west, reappearing in the banks of the Esk. It is first seen again at the borehole put down in Larpool Wood, opposite the Gas Works, but as this borehole is now full of water, it is impossible to get any account of the strata passed through, nor does any record of the section appear to have been kept. A little further south under the chalybeate spring there is a small square hole sunk, from the sides and bottom of which ironstone nodules with *Avicula braamburiensis* may be found. The top of the shale keeps just above flood-level till we reach Cock Mill, in Larpool Wood, where the waterfall passes over the Moor Grit, and cuts into the soft shales of the Grey Limestone below. Some distance to the south-west there is an interesting series of sections, in Shawm-Rigg Beck, and its tributaries towards Sneaton. Although the entire series may be seen three or four times over, the vegetation is too dense for a detailed section to be measured, but the following is an approximately accurate summary :—

	Ft.	In.
Light coloured sandy shales with thin bands of sandstone, containing a few casts of fossils; at the base is a row of ferruginous nodules crowded with *Avicula braamburiensis*	10	0
Hard calcareous sandstone with bright blue-grey fracture; top often covered with fragments of *Encrinite* stems	4	0
Flaggy siliceous limestone band; *Gervillia acuta* abundant; also *Pecten lens*	1	6
Calcareous shale, about	5	0
Very hard calcareous beds, lower part has a conchoidal fracture	2	0

North of the Esk there are a few sections which show the position of the Grey Limestone, the principal of these is in the bank opposite the iron foundry between Whitby and Ruswarp, where shales with small fossils can be seen; the sandstone above, which is exposed in the railway cutting, is evidently the Moor Grit.

The next area to be considered is the great central portion of the northern plateau of Cleveland, around which the Grey Limestone series forms a thin belt, somewhat broken by faults. The east end of the outcrop is inferred from that of the Moor Grit, the only exposure of the beds below being at Barnby Tofts,* where the shales with *Avicula braamburiensis* are seen. Its course is interrupted by the fault seen in the cliff at Runswick, which throws the beds down some 50 feet to the west. In the deep

* Misspelt *Lofts* on the One-inch Map.

dale just north of Mickleby the Moor Grit has been quarried, and this bed continues to be the only clue to the position of the Grey Limestone Series till its base is seen at the head of Borrowby Dale, in the Newton Sandstone Quarries. Here resting on the sandstone is some carbonaceous shale with soft jet, above which is a small exposure of calcareous sandstone, evidently the base of the Grey Limestone Series. For some distance to the north and west the outcrop can only be inferred from the grit beds above.

At Rousby Mill there is an exposure of Moor Grit and part of these beds, the section being as follows:—

	Ft.	In.
White gannister-like sandstone with plant remains	12	0
Sandy shale with bands of thin sandstone	7	0
Ironstone band, a few small fossils	0	6
Grey sandy shale	0	10
Ironstone band, many fossils	0	6
Shale	6	0
Gritty ferruginous band full of *Avicula braamburiensis*	0	3
Base of waterfall.		

The calcareous beds are seen at intervals further down the stream, and again to the east in Bitch Hill Beck.

The outcrop now trends south-west, evidently flanking an old line of valley, and being completely concealed by Boulder Clay as far as Scaling, where the following beds are exposed:—

	Ft.	In.
Sandy ferruginous shale, nodules in upper part, containing *Avicula braamburiensis, Pecten lens, Gervillia acuta, Astarte minima*, and a few other small fossils	15	0
Calcareous hard sandstone fossils in upper part	3	0
Hard sandy calcareous shale	2	6
Bands of calcareous fine-grained sandstone	8	0
	28	6

The second bed represents the fossiliferous grit that is so strongly developed to the south and west, while the long slab-like beds at the base represent the marl or limestone beds nearer Whitby.

Beyond Scaling, a few small sections are seen in the gullies under Grinkle Park, beyond which the Moor Grit, which is well developed here, is the only clue to the outcrop.

Two of the borings put down by the North Loftus Iron Co. must have passed through these beds, but there is no mention of them. After an obscure course for several miles, a section is met with in the small stream some 300 yards north of Handale Abbey, which is as follows:—

	Ft.	In.
Earthy ironstone nodules, *Avicula braamburiensis, Astarte minima*, &c.	1	0
Shale, ferruginous and calcareous	5	0
Thin sandstone with lines of sandy ironstone	2	0
Calcareous and ferruginous sandstone, very hard	1	6

Thick Drift, again, obscures the ground to the south and west, and the outcrop is approximate only for some distance.

In the small outlier on which Liverton Lodge stands, fossiliferous grit outcrops at the top of the bank above Rosecross Wood, the Moor Grit being also exposed about the Lodge, but the southern portion is again drift-covered.

Along the banks of Kilton Beck, the Moor Grit, with the Grey Limestone below, is clear of Boulder Clay for a considerable distance, the former rock often forming a bold crag. Petrifying springs indicate the presence of calcareous beds, which may be seen below the fossiliferous sandstone at Cabin Hole Quarry. At Scabdale Bower, near Liverton Mill, the following section was measured:—

	Ft.	In.
Sandstone (Moor Grit)	40	0
Sandy shale with hard bands	5	0
Ferruginous band	0	2
Shale	6	0
Ferruginous bands, fossils	0	3
Grey shale	7	0
Fossiliferous, calcareous sandstone	10	0

South of this point the ground is entirely clay covered, the Moor Grit outcropping only in the bed of the stream in Alder Wood; while a little north of this, below Elm Heads, the calcareous base of the Grey Limestone is seen.

The next evidence is at Pissing Scar in Dale Beck, where the same beds crop out. In the other branch of this stream in Kate Ridding Wood, opposite this section, the whole of the lower part of the Grey Limestone is exposed, and some well-preserved fossils may be obtained, the beds having been quarried to a small extent for road-metal. A large fault cuts off the outcrop a little west of these two sections.

Some distance to the north-east the base of the series is visible in Goat Scar Wood, the next clue to the outcrop being the Moor Grit at Kilton. At Crags Hill, near Crags Hall, the fossiliferous grit makes a considerable spread, the same bed coming to the surface a little south of Brotton village. In the railway cutting just south of Brotton Station the following beds are laid bare:—

	Ft.	In.
Hard white sandstone	30	0
Sandy shale	10	0
Ferruginous nodules resting on ferruginous grit, with casts of *Avicula, Gervillia, Pecten,* &c. passing down into a calcareous bed.		

The new pit put down by Messrs. Bell Brothers commences just above the Grey Limestone, the Moor-Grit having been quarried away. In the little stream just west of North Skelton Shaft, the following may be seen:—

	Ft.	In.
Hard calcareous and fossiliferous grit	5	0
Softer and more sandy beds	5	0
Argillaceous shales (Estuarine beds).		

In the shaft, and again in the water-level, the Moor Grit and Grey Limestone were cut through, but no record of their

nature and thickness was kept. For nearly two miles neither of these beds have a clear outcrop; but a good clue is obtained from No. 3 of the North Skelton borings, which pierced both.

On the south bank of Bushy Dale, near Stanghow Ridge, the fossiliferous grit crops out, and is clearly seen abutting against the Moor Grit. There must consequently be a small break in the outcrop here. The ridge itself is formed of the Moor Grit, and as Jenny Frisk Sandstone Quarry is below the Grey Limestone, the outcrop of the latter must be in the bank between the two.

The outcrop here splits into three parts. The first turns round to the east and ends against a fault, its exact position being obscured by clay. The second passes round the head of the dale formed by Lockwood Beck, its course being hidden by sand and gravel till it reaches the fault already referred to, by which it is cut off. The third and main portion of the outcrop continues for some distance under Boulder Clay till Woodhill Gill Quarry is reached, where the sharply defined base of the grit above fixes exactly the position of the Grey Limestone, the water also showing the presence of calcareous beds.

In Tidkinhow Slack the following section was measured:—

	Ft.	In.
Flaggy grit	—	
Sandy shale	15	0
Fossiliferous grit	2	3
Hard blue limestone	0	6
Blue shaly limestone	5	0
Siliceous crystalline limestone	0	6
Ferruginous and calcareous sandstone	5	0

The fossiliferous grit makes a considerable spread on the ridge dividing Sleddale from Commondale, and great blocks of the same bed mark the outcrop on the west flank of the hill. Another similar spread forms the tabular hill on Commondale Moor, and also on the outlier of Kempswithen between here and Basedale. This grit is very hard and well developed in this neighbourhood, and makes a well marked feature in the structure of the district.

Skirting round Raven Gill, above Skelderskew, the Grey Limestone may be traced either by the Moor Grit above or occasionally by the fossiliferous grit. Further east, just above Cobble Hall, is an old quarry, from which the calcareous beds were once obtained and burnt, but the limestone is very impure, and as it was found difficult to prevent the whole running to a slag, the working of it was discontinued. The section is too obscure to be given in detail. The base of the Moor Grit is at the top of the quarry; below this comes the shale with nodules, the calcareous bands being at the bottom. Just beyond this, a fault throws the limestone down to the east, but its position is still clear enough for some distance, although the outcrop above Castleton Station is broken by two small faults. In Haw Ridge Slack bands of flaggy limestone crop out in the small stream, the Moor Grit, which is finely developed, forming a clear upper boundary both here and round Ewe Crag in the adjoining small valley. Just under Lop Hall a fault is seen, passing through

the basement beds of the limestone, and throwing them down some 30 feet. The little gully that this fault crosses gives the following section :—

	Ft.	In.
Soft calcareous sandstone	2	0
Sandy ferruginous shale	4	0
Hard siliceous and ferruginous sandstone with *Gryphæa* in the bedding planes (base of Grey Limestone)	8	0
Sandstone, shaly in parts	10	0
Shale, blue and white	3	0
Sandstone carbonaceous	5	6
Fireclay	3	0
Sandy shale	2	6
Sandstone, soft brown and micaceous	14	0
Grey shale	5	0
Shale, ferruginous above	4	2
Flaggy sandstone	4	6
Coal Seam (11 inches of Coal)	1	7
Underclay	1	3
Shaly sandstone, vertical *Equisetites*	1	6
Sandy shale	3	0
Sandstone	2	6
Shale with "pipes" of coal	15	0

It is impossible to obtain a complete section of the Grey Limestone Series here, but in Clither Beck, to the north-east, the beds above, which are sandy and more fossiliferous, may be seen. The lime has evidently been to a large extent dissolved out, the upper part being sandy and ferruginous, but only slightly calcareous. South of Danby Beacon the shale with nodules and the fossiliferous grit are seen at intervals, the outcrop being very clear as it passes into the next map, and re-enters at Stonegate. The fossiliferous grit crops out in the road down to the Mill, and can be followed, as well as the shale above, till they are cut out, or rather thrown down, by a considerable east and west fault.

A small patch of the Grey Limestone Grit enters this area just at the point where the Dyke leaves it, which is part of a large outlier to the south.

There is a detached outcrop of the Grey Limestone Series on Eston Hill, having a roughly elliptical form. This is much faulted, the breaks being clearly shown by the fossiliferous grit, which is here strongly developed, and is coarser than in any other portion of its outcrop, the grains of quartz being often as big as peas. It is also characterised by the abundance of casts of fragments of *Encrinite* stems. These features may be well seen on Normanby Moor, and also to the south-east of Upsall Shaft. It is very doubtful if any limestone exists below this grit, as no mention of it is made in the boring on Barnaby Moor, which must have passed through it.

Estuarine Series.—The Grey Limestone Series is succeeded by a considerable thickness of sandstone and shale, probably some 200 feet thick. These beds are often known as the Upper Estuarine Series; but this name is liable to cause confusion, as it has already

been used for a series of strata in the midland counties that are not homotaxial with those of Yorkshire.

At the base of the Estuarine Series in this district is a rock of peculiar appearance, known as the Moor Grit, which can be generally recognised in a large exposure. It is a hard white siliceous rock, much worked for different purposes, according to its local character. The great paving slabs at Whitby Quay and many of the most durable buildings are made of it, while in the central part of this area it forms a very hard road-metal. It is seen in Beacon Hill and Moorgate Lathes to the east of Whitby, and again about the ship-yard and in Larpool Woods, where it is well developed. The new railway cutting on the opposite bank of the Esk passes through this bed: it is here evidently of considerable thickness.

In the main outcrop it has been quarried about East and West Barnby, where it is very hard, and is used for road-metal, but at the head of Barnby dales, north of Mickleby, it is a softer siliceous stone, and is quarried for building purposes. Over Ellerby Moor and Newton Mulgrave is has been worked for road-metal for many years, occurring in thin wedges, very hard, and breaking like a chert. It is known locally as the "White Flint." When fragments of this rock weather out on the moor they have quite a glassy surface, and appear almost indestructible. To walk over a road mended with this stone is often painful, as the little glassy lumps stick up, and remind one of the old penance with peas in the boots. About Rousby Mill, where the Moor Grit is of great thickness, the lower portion is flaggy, the middle a hard massive sandstone, wedges of "White Flint" forming the upper part. A little south of this the middle part is a true gannister with rootlets, and could be easily ground and crushed. About Grinkle Park this bed is a thick gritty sandstone, and has been extensively used for building. It appears softer and more flaggy at the outcrop in Grinkle Lane, after which it presents no feature of particular interest for some distance.

At Nab End Wood, opposite Kilton Castle, the Moor Grit forms a bold precipitous scar, and is of considerable thickness. This scar continues as far as Liverton Mill, and the rock has been much quarried in its course. It forms the bed of the stream in Cow Close Wood, where it is again flint-like; it also presents a similar appearance in the west bank of Hagg Beck. Kilton village stands on the Moor Grit, which is seen in several places about Lumpsey. It was passed through in North Skelton Shaft, and a considerable quantity of the hard "White Flint" was met with in the water-level of that mine. Wygrave Quarry is in this bed, which must make a considerable spread under the drift here, for it was the first rock met with in sinking Lingdale pit. There are numerous openings in it on Stanghow Ridge and about Kate Ridding; Pissing Scar, near the latter place, is also formed by it. There are several quarries about Tidkinhow, and a very fine section is exposed at the head of Lockwood Gill, where the "White Flint" at the top is well developed.

Blocks of white grit with a glassy surface mark the outcrop over Commondale, on the east side of which, the "White Flint" has been quarried, occurring in wedges in the softer grit. This bed maintains a very uniform character in the great bank overlooking the Esk on the north side. About Danby the numerous quarries for road-metal mark its position well. Some of these fragments of the White Flint are so compact and semicrystalline as to be translucent in thin flakes. A specimen from the quarry above the road going from Danby Station to Easington was given to Mr. J. A. Phillips, who thus describes it.*

"It is white and fine-grained, being often so compact as to be entitled rather to the name of quartzite than to that of grit. . . .

"Under the microscope this rock is seen to be almost entirely composed of transparent colourless quartz, of which the largest pieces are about $\frac{1}{75}$ inch in diameter, and of which the angles are usually more or less removed. Around and between these grains a deposit of transparent crystalline quartz has taken place, thus forming a cementing medium. A few small garnets are present, but no fluid cavities with bubbles were observed, although some of the quartz encloses minute crystals of a yellowish mineral which I have been unable to identify; these are exceedingly minute, often not exceeding $\frac{1}{10000}$ inch in length. Many of the smaller grains in this rock exhibit, when examined in polarized light, that complex structure so frequently observed in the quartz of clay-slates and other somewhat similar rocks."

Round Lealholm Rigg past Stonegate to the great east and west fault, the road-metal quarries indicate plainly the course of this rock; on the east side of the valley the outcrop can also be easily followed above Westonby House, after which the rock gradually becomes more flaggy, and keeps so for a considerable distance, as may be seen in the quarries south-west of Fishburn's Plantation. On the north side of Egton Low Moor the outcrop is entirely drift-covered, and can only be approximately fixed.

Calf Hill Crag, near Eller Park, is formed by the Moor Grit, which is here a fine massive rock, and continues to form the upper part of the east bank of the stream as far as Eller Park.

This bed has also been worked in Dale Beck Quarry, west of Mickleby, where it occurs in thick flags.

On Skelton Hill weathered fragments of the "White Flint" are seen, but the bed as a whole is poorly developed; the same may be said of its outcrop on Eston Moor, where the Grey Limestone Grit overshadows the outcrop of the adjacent rocks.

The Estuarine Beds above the Moor Grit consist of thin sandstone and shales. The former are very hard and close grained, being often used for walling and moor enclosures. The latter are scarcely true shales at all, but rather hardened clays, weathering into small prismatic fragments. As a rule, they are nearly white and look rather like putty, but sometimes they are red or mottled, somewhat resembling New Red Marl. They

* *Quart. Journ. Geol. Soc.*, vol. xxxvii., No. 145, p. 16.

are quite destitute of lime, which causes them to form a very barren soil, being in addition very wet and cold. When ground, a very fine brick can be made from these beds, as may be seen near Egton.

The only exposures about Whitby are in Larpool Woods, and on the west bank of the Esk opposite the ship-yard.

On the great central plateau the chief exposures are in the various streams between Mickleby and Ugthorpe, and in Wapley and Cow Close Becks.

About Kilton Pit the shales are exposed in the railway cutting and on several of the small surrounding hills. Some of this shale when ground and burnt was found to make a durable fire-brick. About Danby Beacon some of the footpaths have been deepened by the rain, and a nearly complete section can be seen on the west side of the hill. As the country is quite free of drift, the kind of ground that these beds form can be easily studied. The cold wet white shale is seen between the roots of the ragged heather, which has all the appearance of struggling for existence. A great spread of these strata gives a dreary landscape that is not easily forgotten. Within a few feet of the top of this series is a bed of hard white compact grit, very like the "White Flint." Its hardness causes its outcrop to be very clear when free of drift, and fixes very well the upper limit of the Estuarine beds, but it is so frequently drift-covered, except where it rises to more than 800 feet above the sea-level, that there are very few exposures of this series.

Cornbrash.—At the top of the Lower Oolites is a marine bed which Professor Phillips has called the Cornbrash. It usually consists of about 10 feet of soft shale, resting on four feet of sandy ferruginous marl. Its outcrop forms a ring round the base of the Kellaways Rock. As it is always seen, where a clear section can be obtained, we have not hesitated to draw it when the base of the latter rock can be accurately fixed.

The following are the best sections of the Cornbrash. On the east side of the road from Liverton to Danby, a little south of Elm Ledge Quarry, shales with ferruginous fossiliferous nodules are seen, with a marl bed below; the marl containing *Ostrea flabelloides*, *Terebratula* sp., and an echinoderm, fragments of the latter occurring at almost all exposures.

The next observed outcrop is just below the letter "R" in Danby Low Moor on the One-inch Map, the marl being again exposed. On the east side of Danby Beacon the shale, marl, and the hard white sandstone are all clearly seen; fragments of the marl occurring on the path along the east side of Brown Rigg. On the north side of Hardhill Beck, opposite Green Houses Quarries, the following section is exposed:—

	Ft.	In.
Hard sandstone, Kellaways Rock	—	
Finely laminated shale	10	0
Ferruginous marl	4	0
White shale	5	0
Hard white sandstone	2	0

Both the shale and marl crop out about Green Houses, but further east there is too much talus and drift for any section to occur at this horizon. About Ugthorpe, the base of the Kellaways Rock not being clear, the Cornbrash is not mapped.

Middle Oolites.

Kellaways Rock.—This is the highest geologically of the solid rocks occurring in this area. It is a bed of close-grained sandstone, well-bedded, with lines of small quartz pebbles, and forms an exceedingly dry soil. The change in character between this and the ground below is most marked, and considering that the Estuarine Shales below are the wettest of all the strata in this country, it is at once seen how easily this rock can be recognised. It is possible to tell at night when crossing a driftless area of Kellaways Rock, both from the extremely short heather with which it is covered, and the peculiar scrunching of fragments of the rock under the feet.

One of the best and most characteristic exposures occurs in Dimmingdale Quarry, half a mile south of Freebrough Hill. The upper part is here hard and siliceous, with small quartz pebbles; but its most marked feature, and one which extends for many miles, is the curious manner in which the rock is absolutely riddled by the hollow casts of *Belemnites*, the whole of which have been dissolved away. Sometimes as many as 50 of these casts occur in a cubic foot of the bed, and specimens of from three to six inches thick will have a dozen cylindrical perforations right through them. This clearly proves that the Kellaways Rock at some depth below the surface must be a calcareous sandstone, its extremely porous nature being in part due to the dissolution of lime.

Along the bedding lines *Pecten demissus*, *Pecten fibrosus*, *Avicula braamburiensis*, *Gryphæa* sp., &c., are very abundant, fragments of *Ammonites* sp. and *Trigonia* sp. being not uncommon. The rock is evenly bedded, and much of it makes good hard flags, extensively used for dry walling and for footpaths. Water oozes through the porous grit, and is at once thrown out by the Cornbrash shales, and this wet line gives a well marked base to the rock.

There is a small outlier of Kellaways Rock at Oven Close Hill, brought down by a fault; only the west side is clear of drift where it has been quarried for dry walling, but the shape of the ground clearly shows the line of outcrop.

Smeathorns Hill, south-east of the Lockwood Beck Reservoir, is another outlier in which there are several small quarries. It has been partly reclaimed, the walls being built of this sandstone. The fault bounding it on the west is clearly seen and easily followed.

Brown Hill is a small patch of Kellaways Rock cut in two by a small fault. At its south-east end is a quarry in the "Belemnite

Rock." Moorsholme ridge shows well the dry nature of the ground formed by this bed; but perhaps the most interesting of all the exposures is the small outlier of Freebrough Hill, which consists of Estuarine shale capped by the Kellaways Rock. The following fossils in casts are found in great abundance; *Pecten demissus, P. fibrosus, Avicula braamburiensis, Ostrea undosa, Gryphæa* sp., &c. This hill may be seen from a great distance; and meetings of the inhabitants are supposed to have been held here.

After passing two more small outliers, we come to a great spread of this rock, which, on its southern and western outcrop, is quite free of drift. Close by the sharp bend in the Whitby Road where it crosses the outcrop, the Kellaways Rock has been extensively quarried for flags; there are also good sections in Elm Ledge Quarry, and in an opening at the south end of Nean How Ridge.

At Green Houses Quarries the upper part is exposed, and is a flaggy marly sandstone, containing a vast number of fossils, but unfortunately they are mostly casts. The chief are *Pecten demissus, Pecten fibrosus, Trigonia* sp., *Gryphæa* sp., *Belemnites* sp., and *Ammonites* sp. There are also quarries in this rock at High Tranmire and Wood Dale House.

On Easington High Moor is a double line of pits called "Ancient British Settlements."* This term has been applied to many similar holes, and in every case they occur immediately above a seam of ironstone, and doubtless are nothing but ancient workings for iron ore. On the coast near Scarborough, the junction of the Oxford Clay and Kellaways Rock is marked by a thin seam of clay ironstone, and this same band is seen cropping out in the west side of the hollow, close by these so-called settlements. In the stream close by Wapley Bridge ferruginous marl with a shale top is seen, crowded with fossils, but much decomposed. It is just possible that we have here the base of the Oxford Clay.

The northern extremity of this area of the Kellaways Rock is quite concealed by drift, with the exception of a small exposure in the little stream east of Girrick.

This great spread of the Middle Oolite extends eastward along a synclinal as far as Ugthorpe Mill. The Kellaways Rock is then let down by a fault, which causes another long tongue of it to run under Ugthorpe as far east as Broom House, where it has been quarried. It here lies in a sharply marked synclinal.

A noticeable feature in the map is the great number of indentations in the outcrop of this bed. As they rarely cut below the Cornbrash, they are usually wet from the constant oozing of water, and, in consequence, are generally peat-covered; indeed, most of the peat in this district occurs in hollows about the base of the Kellaways Rock.

* These holes are more or less full of water, and must have been uninhabitable. Their position is such that water must always be oozing through them.

CHAPTER V.

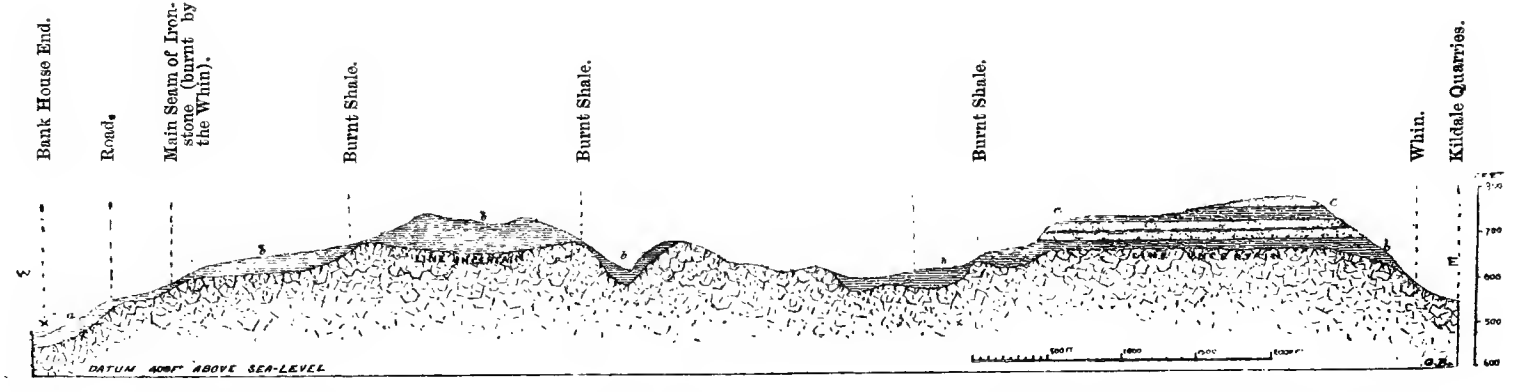
BASALT-ROCK.

Crossing the south-western corner of the area here described, is a nearly vertical wall-like intrusion of "whinstone" or basalt-rock, known as the Cleveland Dyke. It varies much in width, as may be inferred from the fact that at the top of Cliff Ridge, near Ayton, it is only 20 feet wide, while a level driven through it, at the bottom of the hill, proved its breadth to be 80 feet. Another interesting point is the unevenness of its upper surface, as it frequently disappears for a considerable distance, and then reappears. Where first seen, in the western area, it occurs in soft shales, and, in consequence, forms a strongly marked ridge, as is well seen about Langbarugh and Cliff Ridge. The shales protect the "whin," by their being comparatively watertight; but when the dyke occurs in the Oolite sandstones, it is sometimes completely decomposed to a depth of nearly 200 feet. The best specimens of the rock are consequently to be obtained where the Lias Shales form the sides of the dyke, and where they are at a great depth from the surface. Taken as a whole, its course is remarkably straight; but very sharp local bends are to be seen occasionally, as, for example, just west of the Ayton Railway.

As far east as the top of Cliff Ridge the dyke reaches the surface, but does not appear on the east slope of the hill. The Drift makes it doubtful whereabouts it again crops out, but there is a large quarry in it at Slacks Wood. Just beyond this it must again sink beneath the surface, reappearing only at one point in Howl Road. The calcined Ironstone and several trial-holes show that it has just failed to burst through the solid rock here. After being quite covered for some 300 yards or more, it is seen again for some little distance at Stone Ruck, but its breadth is not more than 20 feet here. Further up the hill a few patches of burnt shale show that it is close to the surface, but in the Oolite capping of Coates Moor it makes no show. Descending into Kildale, it is quarried once more, but for some distance is hardly as much as 20 feet broad. Close by Wood End it is covered by Drift for a short distance, and when it reappears it contains a considerable amount of pyrites, the decomposition of which probably gives rise to the sulphuretted hydrogen spring that issues from the dyke close to the railway bridge. A small outcrop of "whin" is seen on the south side of the railway, near the old fish pond, after which it disappears for more than a mile. Due south of Wayworth is a small scar, in which the dyke may be followed for about 50 yards, again plunging beneath the surface. Some burnt shale marks its position further east, but the dyke itself does not appear till nearly the top of Kempswithen is reached; from this point it is visible for a considerable distance to the east. Two points may be noted at most exposures. The first is the small amount of

Fig. 3.

Section along the Cleveland Dyke.



Section to illustrate the irregular upper limit of the Cleveland Dyke. From near Bank House (one mile N.N.W. of Captain Cook's monument), through the head of Lonsdale, over the east end of the Oolitic Outlier, on which the monument stands, to the quarries at the junction of Kildale and Lonsdale.

× Drift. *a* Middle Lias. *b* Upper Lias. *c* Lower Oolite.

alteration that the dyke has caused in the adjacent rocks, the calcining effect rarely extending for more than a few feet from the cheeks of the dyke. Another curious point is the way in which, for a few yards, the beds dip into the dyke. It looks as though the intrusive rock had contracted on cooling, and dragged down the adjacent rock with it. In no case is the dyke known to lie in a line of fault.

The dyke consists of a bluish-grey rock, rather compact, and having a tendency to conchoidal fracture.* It is finely crystalline, even microscopically, except at the sides, which have a very compact appearance. Scattered pretty evenly throughout are glassy crystals of felspar, some of which show the parallel striations of plagioclase. Other minerals are rare—pyrites, calcite, quartz, mesotype, and pectolite, though found occasionally, may be hunted for in vain, unless a "lucky" spot is hit on. The best place to find such minerals is in Kildale, where there is a considerable number of cavities in the whin about half an inch in diameter. The sides of the cavities are coated with little hexagonal pyramids of quartz, and in the centre is a crystal of calcite, the two minerals being kept apart by a curious layer of a sooty looking substance.

Mr. Teall gives the two following analyses of the dyke at Great Ayton:—

Silica	57·57	59·25
Alumina	14·25	16·75
Ferric oxide	6·04	4·00
Ferrous oxide	3·95	4·82
Manganese oxide	·27	—
Lime	6·87	6·88
Magnesia	4·24	3·81
Potash	1·08	1·92
Soda	2·98	2·56
Sulphur	1·9	—
Carbonic acid	·30	trace.
Phosphoric acid	·15	—
Water	1·25	—
	99·14	99·99

This gives an average of about 58 per cent. of silica, which is much higher than that of a typical basalt. The specific gravity also is lower, being only 2·77. In consequence of this, Mr. Teall proposed to call this rock an augite-andesite, and compared it with specimens, similarly named, from various parts of Europe.

Microscopic characters.—Viewed under a one-inch objective, this rock is seen to consist of a matrix of pale brown tint, intersected by countless little glassy rods, mostly straight, but often curved. Scattered throughout are vast numbers of lath-shaped crystals of felspars, often showing characteristic plagioclase banding under crossed nicols. Granules of augite occur in considerable numbers, mostly having a tendency to form little groups or

* *See* "Petrological Notes on some North of England Dykes," by J. J. H. Teall. *Quart. Journ. Geol. Soc.*, vol. xl., p. 209, 1884.

colonies, without actually touching one another. Here and there larger crystals of augite occur; but, in the slides we have seen, the boundaries seem only well defined when the section is nearly perpendicular to the principal axis. This may, however, be an accident, and not generally true. Magnetite, though an essential constituent, is far less abundant than in the common type of rocks that used to be classed together as basalt. This fact alone would account for the rock containing rather more silica, and having a lower specific gravity than a typical basalt or dolerite. In addition to the above constituents are the microscopic crystals of glassy felspar already referred to, as giving the rock a well-marked character. Mr. Teall described these felspars as follows:—

"Sections more or less parallel to the brachypinakoid appear as large flat plates, having tolerably equal dimensions in the different directions, and polarize in a uniform tint, or else show striations due to twinning on what may be assumed to be the pericline type. This twinning is very irregular as regards the length and breadth of the lamellæ. Sections out of the zone of the brachydiagonal axis are frequently much longer than broad, and they show the striation due to twinning on the albite plan. The twinning is also irregular so far as the width of the bands is concerned. Sometimes the section is divided into two well marked halves; but, when this is the case, each half usually contains a few very narrow bands which extinguish simultaneously with the other half, thus showing that the crystals are twinned on the albite, and not on the Carlsbad plan, as might at first sight be supposed. The large felspars are frequently in the condition of fragments; and sometimes a crystal may be seen to be fractured, and to have had its parts slightly displaced, but not actually separated from one another. The fragmentary state of many of the large felspars, as also the fact that they occur in the same condition at the sides and in the centre of the dyke, proves that they have not been formed *in situ*, but have been brought into their present position from below."*

This breaking up of the larger crystals is well shown in a specimen from Great Ayton. A glassy crystal has not only been broken into two parts which are separated by interstitial matter and augite granules, but each part has been further broken up so as to show under crossed nicols a number of small particles touching one another, but each having its own set of "parallel bands." An interesting feature in this crystal is the occurrence of dark roundish spots, seen under a quarter-inch objective to be brown, rather fibrous in texture, and to have a fringed edge; they are quite opaque. It does not seem easy to determine to which species the felspar crystals belong; but the author quoted above shows that in the only instance in which he made a reliable test the felspar was labradorite. Still, other cases seemed to show that all the crystals were not of this species, the optical properties

* Loc. cit., p. 216.

of some showing a close relation to anorthite. A well marked and common feature of the glassy felspars is their zonal banding, of which Mr. Teall says:—"The outer edges of crystals zoned in this particular manner are frequently ragged, owing to inlets of the ground mass; these inlets, however, are limited to the outer zone, and do not penetrate the central portion. It is clear, therefore, that the outer zone was added during one of the later stages in the process of rock consolidation, and probably after some of the constituents of the ground mass had separated out."

The small, but perfectly formed lath-shaped felspars are, as a rule, about three times as long as they are broad, Teall giving their average dimensions as ·1 mm. by ·35 mm. and ·2 mm. by ·5 mm. Under crossed nicols many of them clearly show plagioclase banding. A large number seem binary twins; but, as a rule, a little short band may be detected in one or other half; a few appear as simple individuals. Forming, as it were, a continuation of one of the long edges of a lath-shaped crystal, are a considerable number of long microliths; these look like long glass rods with badly defined edges. Such microlites, often longer than any of the well defined crystals, also occur independently; they have a straight extinction. Sometimes four of these little glass rods are so arranged as to define a perfect lath-shaped crystal, the enclosed space consisting entirely of interstitial matter. In other cases three sides only are defined, while two rods will mark the parallel sides, or even only one angle of a crystal. They may, in fact, be said to form skeleton crystals. The finest examples of the microlites are seen in the interstitial matter, which seems, under a low power, a darkish tinted granular mass, as full as possible of these tiny glassy threads. The latter are often curved, lying close together in a little colony as it were, strongly suggestive of some of the forms shown in Dr. Sorby's paper on "Crystals in Blow-pipe Beads."* A section of slowly cooled and very crystalline Cleveland slag shows several interesting points of resemblance to the interstitial matter of the Cleveland Dyke. The latter is described by Mr. Teall at considerable length in the paper referred to above.

Quartz is frequently seen under the microscope, though not visible in hand specimens; there seems some doubt how much of it is of secondary origin. Biotite also occurs in well defined crystals, but we have only seen one crystal that we could be sure of in three slides. This, like pyrites, is probably a "local accident," that is, it may be fairly common in one or two places, but it is a lucky chance if we hit upon them. This remark applies also to a large hexagonal yellow crystal that was found at Ayton. It cleaved parallel to the principal axis, but had curved cleavage faces.

* *See* Monthly Microscopical Journal, 1 June 1869.

CHAPTER VI.

SUPERFICIAL DEPOSITS.

Glacial Beds.

With the exception of a few small isolated areas, only the high ground about the south and central portion of Sheet 104 is free from glacial deposits. These are divided into three parts:—

1. Upper Boulder Clay.
2. Middle Sand and Gravel.
3. Lower Boulder Clay.

But the first and last cannot be separated on the ground, except where large exposures occur.

Lower Boulder Clay.—This is usually a dark chocolate coloured clay, but its colour varies somewhat, the lower part, near Whitby, being of a reddish purple colour. It contains boulders sometimes of great size, derived from distant localities. As a rule, where the clay is thin, it is so largely made up of the underlying rock, or the rocks a little to the west, that their nature can be at once inferred. Over the high ground, formed of the Lower Oolite sandstones, the drift is, on the whole, more sandy, and is largely made up from those beds. In the neighbourhood of Whitby the erratic blocks are, for the most part, small; the most common are fragments of the hard calcareous bands in the Lower Lias. In these *Gryphæa arcuata* is found; indeed, the finest specimens of that fossil may be obtained from the Glacial deposits. Large blocks of sandstone of local origin are rare, and we should naturally not expect large fragments of shale. But the unexpected does sometimes happen, even in Geology, and close by the Whitby Workhouse is a phenomenon not occurring elsewhere in this district. A great transported mass of the Jet Rock may be seen here which must have travelled a mile or two, perhaps more, to get into its present position; the solid rock beneath belongs to the Lower Oolite. Fragments of the shale can be seen on the road side, and a considerable quantity of jet was obtained from it.

In making the saloon in the cliff face at Whitby, a considerable amount of Lower Boulder Clay was excavated. The number of foreign boulders was not great, the most common were of Carboniferous Limestone, usually polished, and striated; Magnesian Limestone fragments were not uncommon, and occasionally small fragments of the Yoredale Cherts, and Sandstones, and of Shap Granite were met with. Patches of Lias Shale occurred here and there, completely smashed up, but the included fossils showed them to belong to the Lower Lias, about the horizon of the *Gryphæa arcuata* limestones. A good deal of this clay was wedged down, having naturally an almost vertical face; and in consequence clean dry edges were shown. In the face thus formed, hinges of a shell, apparently *Tellina balthica*,

were fairly common, lending some support to the idea that this clay contains ploughed-up portions of the sea-bottom; there was no evidence of stratification.

The Lower Boulder Clay caps the cliffs at Whitby on both sides of the Esk, it then descends on the west till it reaches sea-level, and forms the base of the cliff as far as the Battery. Here a small patch of rock occurs, but the drift soon descends to the beach once more. From Upgang to Saltburn the cliffs are mostly of rock, with a capping of the Lower Boulder Clay. In Runswick Bay, however, the central part of the valley is entirely drift filled, while, on the other hand, the summits of Rock cliff and Hunt cliff are quite clear of these deposits. From Saltburn to Redcar the cliffs are entirely composed of beds of Glacial Age, generally with a slight capping of Blown Sand. About Redcar, the many superficial openings show that blocks of Magnesian Limestone are very abundant, whilst Shap Granite and Mountain Limestone are by no means uncommon. About Saltburn and Guisborough drifted blocks of the Main Seam frequently weather out at the surface of clay fields. We may here remark that when the drift was dug away at Hob Hill, the Ironstone was found to be deeply grooved, the direction of these hollows running roughly N.W. and S.E. That the ice ground over the rocks of this area with no slight force is proved by the fact that at Eston Hill a strip of the Main Seam, some 150 yards long, 50 broad, and 11 feet thick, has been bodily lifted up the face of the hill to a point about 150 feet above its natural outcrop.* On the high ground about Moorsholme, Wapley, and Rousby Moors, great quantities of the local rocks occur in the drift, foreign boulders being comparatively rare. Among the areas comparatively free from drift, we may notice the tops and steep northern faces of Eston and Upleatham hills. With the exception of the small point at Eston Nab, occasional pebbles of foreign rocks show that a thin coat of drift has once existed here. But on the high ground above Guisbrough, on Moorsholme High Moor, and on Danby Low Moor, we have a very different area. There can be no doubt that this high ground, at present more than 850 feet above sea-level, has not been glaciated, as not a single foreign pebble can be found. Moreover, it was not what is termed locally glaciated, for had it been, the Moor Grit would have shown this, at any rate on the west side of Commondale, where this quartzite-like rock has a considerable bare outcrop.† Briefly, the drift becomes very thin at 600 feet above sea-level, and disappears altogether above 850 feet.

* This boulder is seen just above Park Farm.

† On the top of a hill, 2,000 feet above sea level, near Hawes Junction, a similar siliceous rock is beautifully polished and striated; but no foreign rocks occur at anything like this height.

Middle Glacial Sands and Gravels.—This name is applied to a thick mass of current-bedded sand and gravel that lies between the two Boulder Clays, and as these two clays have in this area a very distinct appearance, there should be no confusion as to the meaning of the term. At the same time, it is used in a local sense, and need not necessarily be of quite the same age as beds similarly named in another district, it is strictly a "convenient name." The series usually consists of sand and gravel, but occasionally at their base is a finely laminated or "leafy" clay, with cores of sand, but so far as we know never containing boulders or pebbles. The sands and gravels are well seen in the cliff, west of Whitby, where they are often as much as 50 feet thick. It is evident that they are here, to a large extent, the result of the denudation of the clay beneath, as they contain pebbles of the same foreign rocks. A peculiar feature of the sand is the quantity of coal in it. The top and bottom are usually fine sand, the coarser gravel occurring in the middle. These beds form a bold hill, about Sneaton Castle, rising up from beneath the Upper Clay.

Where the base of the cliff is formed of drift deposits, as at Sandsend, Runswick Bay, Skinningrove and Saltburn, these sands and gravels are usually seen resting on the clay, and may be followed for some distance up the valleys that debouch at these places, but the outcrop is often too thin to be shown on a one-inch map. A long strip of ground to the north of Eston is composed of Middle Glacial beds, and a small patch of them occurs on the top of Lazenby Bank Wood, in Eston Hill. About Guisborough they form a great spread, small dunes of the sand cropping up here and there near Pinchinthorpe. Just south of the great hill through which the dyke passes, is a ballast pit in these beds, from which *Tellina balthica* may be collected in great numbers. This section is very interesting, as it is the first of the great fringing masses of sand and gravel that occur along the Oolite and Lias escarpment, attaining their greatest development between 400 and 600 feet above sea level. Some fine exposures of Esker-like masses of similar beds occur on Stanghow Moor, above Lockwood Beck Reservoir. The openings show the gravels here resting on Lower Boulder Clay, and from the finer seams of sand *Tellina balthica* may be obtained. The great spread of gravel shown on Rousby High Moor and about Wapley Moor is, as a rule, rather flat, but where it passes into the head of a valley, similar Esker-like hills mark its position. From the south end of Easington Moor these beds can be traced into Eskdale, where they are clearly seen under the Upper Boulder Clay, and it is from this evidence that we know the gravels on the moor top to be of middle glacial age, as they never have any clay above them at such heights.

Due north of Guisborough is a bed of finely laminated stoneless clay, from which bricks are made. It lies between these sands and gravels and the Lower Boulder Clay. In the adjoining district to

the west, this laminated clay attains a great thickness, and covers a large area. More details of it will be given in the Memoir on that country.

Upper Boulder Clay.—This is a light red clay, with small stones occurring sparingly in it, but, as a general rule, it contains no large boulders. From its comparatively stoneless nature, and from being somewhat lighter in character than the clay below, it is often used for brickmaking. It can only be found capping those cliffs that consists entirely of Glacial deposits, such as the bay west of Whitby, Runswick Bay, and the cliffs west of Saltburn. It occurs extensively on the lower ground capping the ridges between the various streams, but it does not seem practicable after leaving the cliffs to separate it from the Lower Boulder Clay. On the higher table-land there are a number of sections in various places, which all tend to prove that no Upper Boulder Clay exists at heights much, if at all, above 400 feet.

These drift deposits have played an important part in modifying the general features of Cleveland, changing completely the character of its valleys, and even altering the direction of flow of its streams. For if there is one point quite peculiar, in England at any rate, in the scenery of the district, it is the extraordinary number of rock gorges through which the streams flow. These gorges are in every instance simply due to the blocking of a pre-glacial valley with drift deposits. This feature extends to the largest stream in the district, and to the smallest hollow, for many of the smaller gorges are not 50 yards long. In order to understand the phenomena of these pre-glacial valleys, it must be understood that they are considerably lower than the present ones. This may be shown over and over again. For instance, in such cases as the bay west of Whitby, the drift is obviously below sea-level, and in dredging, the bottom is found to be strewed with big boulders, no rock being known to exist there. But it is from mining evidence that we get the most conclusive evidence of this. A series of borings just to the west of this area proved the old Tees valley to be 90 feet below present high water mark. Indeed, one boring was said to go more than 200 feet into Boulder Clay, but there is little doubt that the greater part of this was the New Red Marl. In Tockett's Mine a level was driven from the pit bottom, which, after being in rock for some distance, passed for a 100 yards in loamy sand, thus proving an old valley, much lower than the stream close by. A series of borings in the royalty and at the south end of Upleatham Hill proved the old valley to be nearly 100 feet below the present stream (Eller Beck).

A similar state of things is proved by the shafts in the Boosbeck Valley, and, in fact, in every instance where mining operations have been carried on across these valleys. These facts show at once that if a stream cuts through the rock anywhere, it can only be because it is flowing to one side of its old course. The first

instance of this is the River Esk, which, at Ruswarp, is approximately in the centre of its old course, and shows no rock. But further north it begins to flow between steep rock banks, which, near Whitby, are nearly vertical. Its pre-glacial course was to the west of the town and into the sea, where the cliffs are entirely composed of Glacial deposits. A deep well sunk in this old line of flow went down a great depth without meeting with any rock, but the exact details we were unable to obtain.

The two branches of Raithwaite Gill flow partly in the old line of valley, but as they near the sea, the western one has evidently cut out a new rock channel. The old valley passing through Mulgrave Woods was originally drained by one stream, but now two flow through it, kept apart by a narrow ridge of drift, on which Mulgrave Castle stands. This ridge is being rapidly denuded away, and in some places, the two streams are so close that their reunion does not seem far distant. As might be expected, the north bank of the north stream, and the south bank of the south stream, both often present steep rock faces, the denudation having begun on the two flanks of the old valley.

It is, however, in connexion with Runswick Bay, that we see the greatest change produced by the blocking effects of the Boulder Clay. The streams at present flowing into the sea here are so small that they are manifestly incompetent to have cut out the large bay, and we must look for its cause elsewhere.

At Staithes a considerable stream flows out to sea, and following it inland we find, at first, its sides are almost cliff-like in character. The rocky banks become lower as we approach Dalehouse, and beyond that is a great mass of drift, evidently marking the site of some old valley. Staithes Beck then is entirely post-glacial; and we find from mining evidence that the streams which now unite to form it formerly flowed past Hinderwell and out to sea at Runswick, for a boring near Hinderwell went through nearly 200 feet of drift without meeting any rock. Borrowby Beck flows as nearly as possible in its old line of valley, but Easington and Grinkle Becks repeat the phenomena seen in the Mulgrave Woods, each flowing at one edge of the old valley, and having a ridge of drift between them. The short tunnel on the Grinkle mineral line pierced this ridge a few feet only above the stream. It was driven entirely in the loamy sands of Middle Glacial age, which, as usual, were found to be "quick." It is evident that the whole of the Lower Boulder Clay beneath would have to be sunk through before reaching any rock. The stream flowing into the sea at Skinningrove, which now divides into two at Liverton Mine, formerly split up further north, and the course of the eastern valley was proved in one of the new engine-planes, driven across it in Loftus Mine. Loftus Beck, which flows roughly parallel to, but south of, this line of old valley, is cut entirely in rock. The most picturesque example of these geological phenomena is seen in Kilton Beck. Here the stream has deviated considerably to the east, as is well shown by the outcrop of the Grey Limestone. The Moor Grit, immediately above the last-named bed, is a very

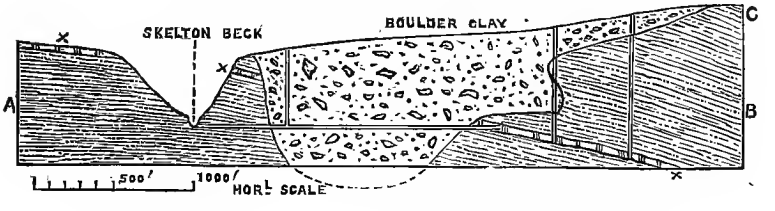
massive rock, and the east side of the valley is consequently capped by bold crags for more than a mile, both sides being densely wooded.

Hagg Beck keeps mainly to its old course, but in Avens Wood and Girrick Wood are fine examples of gorges cut in the Estuarine shales. The great Boosbeck Valley has been so completely filled with drift deposits as to force the stream that eroded it to cut an entirely new course, forming for itself a channel through the solid rock at Slape Wath, whence it flows by the west side of Skelton Hill into Ellers Beck, and so to the sea.

The most interesting example of a pre-glacial valley occurs near Skelton Beck, the former position and extent, and approximately the shape of the old valley having been proved in mining operations. A long level was made from Marske Mill, first in a south-westerly direction, and then turning a trifle east of south. This was driven through drift deposits for a distance of nearly 900 yards, so as to pass under a series of borings, which had already revealed the fact that an immense mass of rock was absent, and its place to a great depth taken by clay, sand, and gravel.* The ground at the surface does not give the least indication of the great valley beneath; which, when occurring on so large a scale as this, is unusual. The explanatory diagram (Fig. 4), in which the vertical scale is three times the horizontal, shows at a glance

Fig. 4.

Pre-Glacial Valley in Skelton Beck.



C Estuarine Series. × × × Main Seam of Ironstone.
A B Lias Shale.

the relative sizes of the ancient and modern valleys. The position of the central parts of the former is made about 90 feet below that of the latter, repeated borings in this valley having shown this to be approximately the difference in depth between them.

One of the strangest facts brought out is the overhanging bank of Alum Shale, which was proved in what is, in consequence, known as the cliff bore-hole. The diagram shows this very well, but the exact amount of projection could not, of course, be proved.

A small branch of this old Skelton valley was proved in Tockett's Mine. The main level into the Upleatham royalty cut

* This is the phenomenon so often called "Clay Wash" by miners and engineers; it is, of course, a pre-glacial valley.

through a "wash," about 150 yards long, the central part of which was filled with a sandy loam. The sides were composed of strong clay, resting in either case against a steep rock face. This level is here about 70 feet below the bottom of the modern valley close by, but obviously it does not reach the base of the old valley, which must be somewhat deeper.

Phenomena similar to these may be met with in the district around Guisborough, but they call for no special notice. The only other modern gorge of any interest, is that of the Leven in Kildale, which is extremely beautiful. Its post-glacial age is very apparent, the central part of the old valley being completely blocked with gravel.

It may not be out of place here to show how to fix approximately the position of one of these old "Clay Washes." Take Skelton Beck as an example. Proceeding up the stream, its banks are cut entirely in rock till Rigg Wood is reached. Here the left or south bank is entirely composed of drift, so that it is obvious that a drift-filled hollow lies on the left hand. A similar phenomenon is seen at Marske Mill. A little beyond this, in Thorny Close Wood, a small stream joins the main one. At first this flows between rocky sides, but these suddenly widen out, and are composed entirely of drift. It is evident then, that this little stream in its upper part is crossing a clay wash. On approaching Skelton Mill, the valley suddenly widens out, and the drift completely conceals the rock. We have evidently entered the old valley once more. By noting the points of junction of the rock and drift on each side of the stream, and joining these up, we get a "pointer" showing the position and direction of one edge of the old valley.

Post-Glacial Beds.

Raised Beach.—A short time since, our attention was called to a small patch of sand into which a considerable amount of clay had filtered.* This is seen about 30 feet above sea-level at Saltburn, the road from the Town to Old Saltburn passing through it. On examining this deposit, it was found to contain a vast number of recent shells, of which the most abundant are:

Purpura lapillus.	*Natica globosa.*
Littorina littoræa.	*Lachesis minima.*
Trochus cinerarius.	*Cyprœa europœa.*

Now, a very remarkable point about this deposit, is the entire absence from it of any of the shells most common on the beach below, such for example as *Solen ensis*. It is clear from this, that there must have been a considerable difference between the conditions under which this raised beach was deposited, and

* Dr. Veitch, of Middleshrough, first called my attention to this. I am indebted to him for the list of shells, and also for much other local information. See also his paper "On the Raised Beaches on the North-East Coast of Yorkshire." Proc. Yorkshire Geol. Soc., N.S., Vol. viii., Pt. ii., p. 221 (also p. 220), 1883.

those at present existing on the foreshore. This small patch of sand covers a small cresent-shaped area about 100 yards long and 50 broad, its average thickness being about 5 feet. Traces of it may be found in Cat Nab, and on the face of the cliff further east, as far as the path to the Coast-guard Station, showing that it must formerly have been of much greater extent. On making the survey of this district we accidently overlooked this interesting little relic, the fact that nothing of the sort occurs on the rocky cliffs, leading us to suppose that a raised beach was not at all likely to be preserved if resting on the soft glacial deposits. It would appear as if the scars and cliff at Huntcliff, and the scars at Redcar broke considerably the power of the currents along the coast, and so reduced the rate of denudation in this little bay.

Alluvial Deposits.—In the case of most of the small streams in this district, the fall of the water is so rapid, that there is little or no Alluvium. The Esk, however, about Ruswarp, becomes tidal, and the soft banks of Boulder Clay being easily cut away, a large hollow has been formed, the bottom of which is filled with flood deposits. For a similar reason there is a considerable spread of Alluvium at Coatham Marsh, about the Tees, but the slag-tips threaten to cover up all this area speedily. A considerable number of small flat-topped hillocks occur on this marsh, to which many fanciful origins have been assigned; but they are doubtless the remnants of an old higher Alluvium, the greater part of which has been denuded away. The presence in them of recent marsh species of mollusca tends to confirm this view.

In the great plain about Guisborough several large spreads of Alluvium are seen, often covered by a peaty soil. The little streams flowing through these have such a small fall that they are easily flooded. Their peaty water-logged nature is in part due to the fact that one or both sides of these alluvial patches are bounded by Glacial Sands, from which water is constantly oozing.

Peat.—The amount of Peat in this area is small, and usually occurs in hollows, there being no hill-peat such as is found on the great fells of the West Riding. The hollows at the base of the Kellaways Rock are usually peat-filled, as may be seen at High Tranmire, and at Hardhill Head, where some fine oaks were dug out; also the source of the small stream that flows past Doubting Castle on Danby Low Moor, whence fine black peat is still cut; and between the two outliers on Moorsholme High Moor. Around the edges of this last peat hollow, the indigenous white-barked birch still grows, and the quantity of white bark in the peat shows the latter to be largely formed of decomposed trunks of this tree.

There is a considerable spread of peat lying on a kind of alluvial underclay in the great Boosbeck Valley, there being little fall for the water towards either end of the valley. Another mass of peat occurs in the nearly water-logged area between Highcliff and Ayton Moor. At the south end of Sleddale, the railway

cuts through a bed of peat which is seen in dry weather to be very full of the white bark of the birch, while further west, just beyond Kildale Station is perhaps the most interesting peat deposit in the district. There is a large hollow in the Middle Glacial Gravel, which fills the whole of the lower part of Kildale.* At the bottom of this hollow a small tarn or pond existed, in which a calcareous mass or marl was gradually formed by the growth and decay of *Chara*, and such marsh shells as *Planorbis nautileus*, *Limnæa peregra*, and *Pisidium pusillum*, and a few others. Above this, is a small sandy underclay, on which the peat has formed sometimes to a thickness of 14 feet. From the lower part of this last bed the horns were obtained of *Cervus elaphus* and *Cervus tarandus*, (Red-deer and Rein-deer).

Marine Warp.—On the west side of the railway near Coatham Marsh, between high and low water marks, is a deposit, often of considerable thickness, of sand mixed with finely preserved specimens of most of the shells that are found living at present in the sea and in the river mouth adjacent; the whole forming a marine warp. This forms a considerable spread about the mouth of the Tees.

Blown Sand.—In the same district, just above high water mark is a line of hillocks or dunes of Blown Sand. Near Lackenby they are of small size and extent, but towards Redcar they form an important feature in the landscape. As the Boulder Clay rises gradually higher above sea level, the cliffs are capped by isolated patches of Blown Sand, which become gradually smaller to the east, and die out before reaching Saltburn.

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* *See* Geol. Mag., Dec. ii., Vol. v., p. 351; 1878.

CHAPTER VII.

PHYSICAL STRUCTURE, FAULTS, &c.

The country here described, owes its general shape to the fact that the strata composing it are nearly horizontal. They appear to have been subjected to lateral pressure from two different directions, probably at different epochs. This has produced two sets of slight bendings, that is two series of anticlinals and synclinals. The more important of these have their axes lying a little N. of W. and S. of E., the others lying roughly N. and S. It is an interesting fact, that the first are nearly parallel to the great whin dyke, though it would not be safe to infer from this an identity of age. The north and south synclinals are so slight, that it is not possible to trace them for any distance. Moreover, when an anticlinal or synclinal axis is crossed by a fault of any magnitude, it seems to be quite destroyed; perhaps the fault is the result of the beds beyond it not yielding to the bending force.

The most southerly and smallest synclinal crosses the highest ground in Cleveland. Commencing near White Cross it passes through Guisborough Moor, and so on to the little projecting table-land formed by the Middle Lias beds near Pinchinthorpe. It is very local, and the dips on either side of it are rarely above two or three degrees. Nearly due north of the eastern end of this is a much more important synclinal. Commencing near Lockwood Beck Reservoir it passes through Great Moorsholme, Scaling Dam, Ugthorpe, and across the Esk to Turnbull's Ship Yard at Whitby.

This trough is abruptly truncated on the east by the Whitby fault, on the west by the Lockwood Beck fault. In it occur the (geologically) highest beds in the district, the Kellaways Rock being practically confined to it.

The third, and from the mining point of view, the most important synclinal, is one that seems to start a little inland from Runswick Bay, but at its eastern end it is not well defined. Westwards, it passes a little south of Hinderwell, north of Rousby, south of Loftus, through Kilton Thorpe, and close to North Loftus and Skelton Park Pit. It has been proved in the south end of Upleatham Hill, and passes into the great hollow at the east end of Eston Hill. Upsall Shaft is sunk in it, and it finally leaves the map at the northern outcrop of the Grey Limestone. It may be remarked, that this synclinal is very sharply defined in passing through Eston Hill; undoubtedly owing to the nature of the ground, which is here more than usually faulted, the west end of the hill lying between two large trough faults.

Of the north and south synclinals, only two call for any special notice. Of these, the best marked extends from Saltburn inland, close to North Skelton Pit, and so on to Lockwood Beck. The other, commencing in Runswick Bay, passes through Mickleby,

and a little east of Ugthorpe. With these local exceptions, the beds may be said (on the whole) to rise steadily to the west, the small height of Eston Hill being due to the fact of the ground being locally faulted down.

There is one anticlinal, which though entirely concealed by drift calls for special notice. It must occur a little inland from Redcar; on the north side of which the beds dip north at an unusually high angle, sometimes as much as 15° degrees, the average of the country being between 3° and 5°. These high dips occur in the scars close to the town; but proceeding seawards, the beds become gradually flatter, till at the northernmost scar they are horizontal, if not actually rising to the north. This is a point of some importance, as it has been stated that the Main Seam of Ironstone occurs seaward of this; but with this roll over of the beds, such a thing is impossible, and we do not believe it to be the case. One fact, however, seems pretty clear. These scars are striking across the Tees mouth in such a way, that the Lias would crop out on the other side of it. But, as we know this latter area to consist of beds of Trias age, there must be some large fault to the north-west or west of the Redcar reefs, a fact rendered highly probable by the unusually high dips.

With the exception of the small area west of Guisborough, the country here described is not much faulted; still, breaks in the strata are more frequent than in the adjoining district to the south, where similar rocks outcrop. The first fault met with is that shown on the map, passing through the mouth of Whitby Harbour. The east pier is built on Alum Shale, while the west is on Oolite sandstone. Standing on the pier head at low water, a line of breakers may be seen, commencing at Saltwick Nab, and ending some distance out to sea, due north of the harbour. This marks the outcrop of the Jet Rock, which is abruptly terminated by this fault, for immediately to the west is comparatively deep water. The sandstones and shales in the low cliff under the Royal Hotel are not far below the Grey Limestone, while the Dogger is at the base of the East Cliff. The break here must, consequently, be some 200 feet. Again, the Grey Limestone is seen at the ship-yard, and the Moor Grit above it may be followed some little distance up Spital Beck till lost under drift. Near Moorgate Lathes is a clear outcrop of the Grey Limestone, and descending the stream, lower beds crop out till we reach the Ropery, where the last rock seen is much disturbed. This rock is some distance below the Grey Limestone, while the Moor Grit, as stated before, outcrops a few yards lower down. There must, consequently, be a considerable break here, though its exact position is obscured by drift.

There is a series of small faults about Kettleness Point which are well shown on the scars by the manner in which they shift the outcrop of the various seams of ironstone. None of them have a greater throw than 10 feet, and only one can be traced as far as the cliff-top.

Nearly a mile north of Runswick Bay is a scar known as Lingrow Knock, which can be examined only at low spring tides. It is found to consist of the hard cherty bands and shales at the top of the Ironstone Series, while on the west, almost touching it, is the Jet Rock; there must, consequently, be a break here of from 40 to 50 feet. This fault can be followed across the scars and into the cliff, which it cuts very obliquely, and in which it has caused several large landslips. After crossing Lingrow End it is again exposed in the little gully above Runswick Village, the fault itself being very clear. The Dogger is nearly 50 feet higher on the east side of it than on the west. Proceeding inland, the throw must increase somewhat, for an adit no great distance above sea-level proves the position of the bed last-mentioned, while the foreshore is composed of shale close above the Jet Rock. Its further course is completely drift-covered as far as Northfield House, near which the outcrop of Grey Limestone is clearly broken, the amount of throw being some 30 to 40 feet. At West Barnby, again, the same bed is faulted against the higher Estuarine Shales; but beyond this, its presence is only shown by the fact of its faulting the Grey Limestone. It would seem to terminate against a large east and west fault, having an opposite throw.

In mining the Dogger or Top Bed at Port Mulgrave, a considerable number of faults were encountered. One of these has a throw of as much as 70 feet; but where it cuts the cliff, close to the entrance to the mine, the break is only about 12 feet. It is interesting to note how, in crossing a small hollow, this fault goes from the top of the cliff to the bottom, and up again a few yards further on, in consequence of its low hade. Another fault of 38-feet throw was proved, which seems to die out in a sharp anticlinal in Brackenberry Wyke.

From Old Nab to Staithes, small faults cross the scars at intervals, but none of them have sufficient throw to be capable of being traced inland. From Staithes to Saltburn, only four small hitches occur; one of these, which crosses the scar at Hummersea, gives a deal of trouble in Loftus Mine, though its throw is still small.

In the south-east corner of the area here described, is a well marked fault, passing just west of Ugthorpe Village. The road from the moor to the village keeps on the crest of a flat narrow watershed capped by the Kellaways Rock. On reaching the windmill there is a sudden sharp drop in the ridge, which still remaining of the same shape, becomes rather narrower. A few small openings show the capping rock again to be Kellaways Rock, so that there is a fault here about equal in throw to the height of the bank at the Windmill. Seen from a little distance the position and effect of this fault are peculiarly well marked. Further north it cuts off the outcrop of the Grey Limestone, but as this occurs under drift, the exact position is not clear. That its throw here is considerable is evident at once, and it is possible that the 70-foot fault, proved in Port Mulgrave Mines, may be the

continuation of this break; but so completely is the country obscured by drift that it would not be justifiable to join them up.

To the south of Ugthorpe is a long east and west fault of considerable throw. It is fairly clear that at its east end this is cut out by another fault, as shown on the Map, because by proceeding first up the stream and then down from the moor top, it is evident that while the beds included between the two faults are mostly above the Grey Limestone, those on the south are below it. Indeed, it is not till reaching Wilks Rigg, considerably to the west, that the evidence of the fault becomes easily intelligible. Here is an old flag quarry in which casts of the common fossils of the Kellaways Rock may be found; while, only a little to the south-west, we come upon the outcrop of the white siliceous Moor Grit, the Estuarine Shales above cropping out close up to the quarry. The sharp dip here shows clearly that the disturbance is close to the opening in the rock. From the relative level of the Grey Limestone and the Kellaways Rock the dislocation must amount to about 150 feet. After crossing the great drift-filled hollow at Stonegate, this fault bounds the outcrop of the Grey Limestone for some distance. A little north-west of the last place where the Grey Limestone is seen, we come upon a clear section of the Cornbrash. The base of the Kellaways Rock above can be very clearly followed, till it is cut off by the fault, the position and effect of it being here well marked, and the throw about 200 feet. Further west the ground is much obscured by gravel, but the base of the Kellaways Rock can be followed down Brown Rigg till it is quite close to the fault, which must here have diminished very much in throw.

The fault shown close to Lop Hall on Danby Low Moor is actually seen in the small ditch or sike on the hillside, and its throw shown by the position of the Grey Limestone, the base of the latter being quite clear on both sides of the dislocation.

The two faults further west have a small throw, but are well marked where they cut the outcrop of the fossiliferous grit (Grey Limestone).

A well marked break in the beds is seen near Cobble Hall. The old lime quarry in the hillside is in the Grey Limestone, while the Moor Grit outcrops in the stream some distance below. The amount of throw must here be roughly some 50 feet. In the higher Estuarine Shales, faults cannot be followed on the ground, but the different levels of the base of the Kellaways Rock in Low Brown Hill and Brown Hill mark distinctly the position and amount of the break in the strata here. Further north the fault rapidly dies away, and can only just be made out on the other side of Brown Hill.

Close to the south-west corner of the main mass of the Kellaways Rock is a small detached portion of the same bed, evidently bounded on the east side by a fault. This continues for some distance to the north-west, and must near Freebrough Hill have a considerable throw; in fact, as much as the height of Freebrough, if not more. The Kellaways Rock on Moorsholme Moor

dips sharply north, and would, but for the break in the beds, pass completely under this hill. As this rock actually caps the hill, it is easy to see roughly the amount of the dislocation. The small outlier of Oven Close Hill is evidently bounded to the north-east by the continuation of the same fault.

There is rather a fine section of the Kellaways Rock in Dimmingdale Quarry, which evidently does not reach the base of the bed; but on proceeding a few yards to the south, it is evident that this rock lies at a considerably higher level, and that a break occurs close to the quarry. Its position as shown on the map is equally clear on the ground; indeed, the outcrop of the Kellaways Rock marks the position of the faults in a very vivid manner. This remark equally applies to a rather large north and south fault on the high moor above Lockwood Beck Reservoir, where the dry Kellaways Rock on the one hand, and the wet Estuarine Shales on the other, form a strong contrast in the appearance of the ground. As the Moor Grit may be followed from Lockwood Beck almost up to the Kellaways Rock, the throw must be here some 200 feet; *i.e.*, the thickness of the upper shales. The break must increase in amount for some little distance further north; after which it rapidly decreases, for the northern of the two outcrops in the banks of Hagg Beck on the east side of the fault cannot be many feet below the corresponding outcrop of the Grey Limestone on the west side. Indeed, no great distance beyond this point, there is no evidence of any break at all.

The small fault running from Stanghow Park to Bushy Dale is well shown by the Grey Limestone Grit, which is let down to the north, so that along Bushy Dale it has a double outcrop.

Two faults have been proved in Lingdale Pit, one of which has a downthrow to the south of 45 feet. Similarly in Kilton and South Skelton Mines a few small dislocations in the strata are encountered; but none of them large enough to make any show at the surface.

In the two outlying hills of Eston and Upleatham we have a curious contrast presented. Upleatham Hill, as a whole, is not much faulted, but in the centre of the north face of it there are two faults, which are well marked where they cut the Main Seam of Ironstone. These have been followed into the hill, where they are crossed by a complicated series of small faults, completely breaking up the seam for a short distance; but the effect is only local. The long fault, too, which has been proved for a considerable distance in the mine to the south of Upleatham, has only a throw of some 12 feet.

In Eston Hill we come upon a very different area; in fact, the most faulted district in north-east Yorkshire. The western portion of this hill is let down by two great faults; but only the one forming the southern boundary to the outlier could be followed eastward into the main range of hills. Where this first enters the map, near Upsall Mill, it has the effect of bringing the base of the Oolite against the lowest beds of the Middle Lias, and the throw is consequently rather more than

300 feet. From this point, eastwards, it rapidly increases in throw till, at Osborne Rush Plantation, it must be at least 400 feet. Here we find Oolite sandstones lying against beds well down in the Lower Lias, and we have faulted out some 50 feet or more of Lower Lias, the whole Middle Lias (100 feet), the whole of the Upper Lias, some 220 feet, and a considerable thickness of Oolite. On approaching Scugdale Slack the fault splits up and diminishes in throw. The first offshoot seems to abruptly cut off the outcrop of the Middle Lias, as shown on the map. A small patch of Grey Shale lying between the Oolite sandstone and the lower shales of the Ironstone Series shows the presence of two faults in the wood west of Scugdale, but these reunite before the little stream is reached, the Main Seam of Ironstone resting against the Oolite, and showing a throw of 250 feet. Further east, near North Cote, the Ironstone exactly touches the base of the Oolite, and the amount of throw is only 220 feet; but after this we have no very clear evidence of the position or amount of the dislocation. Guisborough undoubtedly stands on the Lower Lias, while the flaggy beds of the Sandy Series crop out in Tockett's Plantation, and there is every reason to believe that the two are separated by this fault. Owing to the thick cover of drift, there is no evidence of its position between Tockett's Lythe and Skelton Park Pit; but, in the latter, it was proved, the amount of throw being 35 feet. The break is fairly clear in the Oolite escarpment above, in Forty Pence Wood. In Boosbeck Mine its throw has been proved to be only 15 feet, and it is probably this fault that is seen in the sandstone quarry north of Boosbeck Bridge, where there is a break of only a few feet.

In the north-east end of Eston Hill, near Court Green, are two faults both proved by mining. Though one of them throws down to the south as much as 56 feet, neither of them make any show at the surface.

In the Dunsdale area two faults running in the same direction have been proved. The northern one of these throws down north 12 feet. The effect of the southern one has been a matter of dispute; but, after seeing it, we have no hesitation in saying that it throws down north, and has the effect of throwing out the Ironstone altogether on the south side. The idea that the Main Seam was found in the boring at Tockett's Bridge is altogether a mistake.

The series of faults shown on the west end of Eston Hill have all been proved in the mines, but they only show at the surface where they cut the outcrop of the Grey Limestone.

A series of small east and west faults have been proved in Spa Wood Mine, east of Guisborough, but they call for no special notice. With the exception of two small breaks in Urchin Wood and one near Highcliff, the great escarpment south of Guisborough is practically free from faults. South of Roseberry Topping the Middle Lias escarpment is clearly cut by a fault, having a small downthrow to the south.

CHAPTER VII.

ECONOMIC GEOLOGY.

Ironstone.—Cleveland has acquired a world wide celebrity for the production of cheap iron, and it is from the area described in this memoir that almost the whole of the ore is raised. The extent of this industry, and the number of men employed in it, may be best realized from the fact that from the Main Seam of Ironstone alone no less than four-and-a-half million tons of ore are now raised annually.

It is not worth while here to repeat the well-worn story of the various claims to the distinction of "the discoverer" of the Cleveland Ironstone. A full account of it may be found in Bewick's work on the district and in Marley's paper; a short résumé of both being given in Tate & Blake's "Yorkshire Lias." The whole claims may be dismissed by saying that it is not known who discovered it. The are many outcrop-workings in the dales, doubtless due to the superior knowledge of the monks belonging to the different Abbeys in the neighbourhood; but all record of the history of these has been lost. It is hardly a century since furnaces of a very old type were abandoned at Danby, where for generations a small local iron-industry was in existence, and to which reference is frequently made in old deeds and records.

It was not the finding of the ore that was the cause of the establishment of the great Cleveland Industry, but the bringing of its use to a commercial success; and the credit of this was undoubtedly due to the exertions of Messrs. Bolckow & Vaughan, who recognised the splendid situation of the stone at Eston, with all the facilities that the Tees might give for a great export trade, without expensive land carriage. Moreover, the chief cause of failure till then had been in the process used for smelting the ore; the percentage of iron was far lower than that of any in use at the time, and the point of importance was to adapt old methods to the new requirements.

In 1851 Messrs. Bolckow & Vaughan* built the first Middlesbrough furnaces, which were 42 feet high and 15 feet diameter in the bosh, having a capacity of 4,566 cubic feet. They seem to have recognised the great principle that more work could be got out of the furnaces by making them larger, and accordingly, in 1856, they built two furnaces 55 feet high and 16 feet in the bosh, having a capacity of 7,175 feet. In these at first 40 cwt. of coke was required to produce a ton of iron, and the out-put of each was 100 tons a week; but by carefully-conducted experiments they managed to reduce the amount of coke to 35 cwt. and to increase the out-put to 150 tons per week, which at that date was considered a very extraordinary performance.

* I am indebted to Mr. Lawrence Gjers of Middlesbrough for the facts here given.

At this time the furnaces were all open at the top, and the appearance of the country at night gave one the impression of pandæmonium. But in 1856 Bolckow & Vaughan made the first experiments with furnaces with closed tops, and had at the outset much prejudice and many difficulties to encounter. But by the year 1860 they brought the process to a complete success, and the old system was abandoned. The effect of closing the top was to enable them to utilise the whole of the escaping gases, which hitherto were wasted. These gases were conveyed by a huge pipe from the top of the furnace to the boilers and hot-blast stoves, where they were burnt in place of the fuel formerly used. This at once effected a saving of from 10 to 12 cwt. of coal for each ton of pig-iron; besides dispensing with all the labour of stoking. In addition it was found that it required an average of 10 cwt. less of coke for each ton of metal.

Before the introduction of closed furnaces it required 50 cwt. of ironstone, 35–40 cwt. of coke, and 12 cwt of limestone to be used inside the furnace to yield one ton of iron; but as soon as the closed furnaces were got into working order the same yield was obtained from about 25 cwt. of coke with the former quantities of ironstone and limestone.

A great improvement was at the same time effected by raising the temperature of the hot blast. Previous to 1856 this was about 650° Fahr. or "lead heat;" it was now raised to about 1000° where iron pipes were employed; while in the fire-brick stoves it has been brought up to as much as 1300° or 1400° Fahr.

Experiments were also tried with enlarged furnaces, the results of Bolckow & Vaughan's early efforts seeming to point to the possibility of great saving in this direction. What has been done is clearly shown by the following table, giving the dimensions of the best known furnaces in different years.

Year.	Height.	Diameter in Bosh.
	FT.	FT. IN.
1851	42	15 0
1858	61	16 4
1861	60	20 0
1862	75	16 6
1865	81	19 6
1866	95	16 0
1870	85	25 0

The last may be taken as a fair average of the present dimensions of the Middlesbrough furnaces. They have been built as large as 96 feet in height and 30 feet in the bosh, and have yielded good results—indeed, one is 105 feet high—but there seems no doubt that this has passed the point of economy.

When in good working order an average furnace requires about 20 cwt. of coke, 48 to 50 cwt. of calcined ironstone, and 12 cwt. of limestone to produce a ton of pig-iron. The limestone is not usually calcined. The amount of hot air required to be driven

through the furnace is roughly 140,000 cubic feet. Under these conditions a good furnace will yield about 500 tons of iron per week. They have been made to yield 600 and 700; but this is by increasing the pressure of the blast, technically known as "hard-driving." It tends to wear the lining of the furnaces very rapidly, and can only be remunerative when profits are high, a state of things that has not been known in this country for many years.

The raw ironstone is calcined in large cast-iron kilns, to drive off the water and combined carbonic acid. This causes an increase in the per-centage in the ore from about 30 to about 40 per cent. Originally the stone was calcined in heaps; but this, in addition to being a very dirty method, was very wasteful of fuel; kilns were therefore gradually introduced. These at first were of brick or stone, with thick walls, but now the Gjers-kiln is the form usually adopted. This consists of a wrought-iron shell, lined with fire-brick, in shape like a cylinder with a truncated conical base, supported on cast-iron pillars 2 feet 3 inches high. This enables the barrows to be put under the bottom, which has a sliding door, and the former can be easily filled in a few seconds. The kilns are being constantly filled with ironstone and fuel, and the former is calcined in its passage downwards. One ton of small coal is required to calcine about 25 to 30 cwt. of ore. The average size of the kilns is from 30 to 40 feet in height by 24 feet diameter, and one of them is capable of calcining from 800 to 1,000 tons of raw stone per week.

The increased height of the furnaces has been accompanied by an increase in the pressure of the blast from the original average of 3 lbs. to the inch to 5 or 6 lbs. In some cases a greater pressure than this is used, but the advantage of it is a matter of dispute.

When Messrs. Bolckow & Vaughan first began their experiments, in order to obtain one ton of pig-iron some 50 cwt. of coke were used in the furnace, and about 10 cwt. of coal in the generation of steam and the hot-blast; while the whole work is now done by 20 cwt. of coke. This means that under the new order of things the Durham Coal-Field can be made to smelt about three times the amount of iron that it could have done under the old plan.

It may not be out of place here to give a few notes on the structure and chemical composition of the Main Seam. Dr. H. C. Sorby, in his anniversary address to the Geological Society, referring to the Cleveland Main Seam of Ironstone, describes a specimen from Eston Nab as follows* :—

"The iron occurs mainly as small crystals of the carbonate; and nothing can be more clear than that it was collected in its present

* "Anniversary Address to the Geological Society, for 1879." *Quart. Journ. Geol. Soc.*, vol. xxxv., *Proc.* p. 84, by H. Clifton Sorby.

state subsequent to the decomposition of the rock, by the replacement of carbonate of lime by carbonate of iron. This is well shown by the fragments of arragonite shells, which have their surface for a certain depth replaced by dog-tooth crystals, penetrating into them just as in the case of an artificial pseudomorph which I prepared by keeping a portion of Iceland spar for some weeks at a somewhat high temperature in a solution of ferrous chloride. The exterior of the oolitic grains is also replaced in the same manner; but, curiously enough, fragments of Brachiopods and Oysters are not at all changed, thus showing that the chemical action varied somewhat according to the original character of the shell. The characteristic constituent of the Cleveland Hill Ironstone was thus derived partly from mechanical deposition and partly from subsequent chemical replacement of the originally deposited carbonate of lime, which probably thus served to collect together, from associated ferruginous non-calcareous beds, a large part of the iron which the rock now contains, as suggested in my paper in the Report of the West-Riding Geological and Polytechnic Society."*

The following account of the Main Seam is given by Mr. A. Dick:—†

"Chiefly a carbonate of protoxide of iron; lustre, earthy; colour, greenish gray; streak, similar; fracture, uneven, showing here and there small cavities, some of which are filled with carbonate of lime. Throughout the ore are diffused a multitude of small oolitic concretions, together with small pieces of an earthy substance resembling the ore, but lighter in colour. When a mass of this ore is digested in hydrochloric acid till all carbonates and soluble silicates are dissolved, there remains a residue having the form of the original mass of ore. It is extremely light, and falls to powder unless very carefully handled. It contains the oolitic concretions, or else skeletons of them, which dissolve completely in dilute caustic potash, showing them to be silica in a soluble state. Under the microscope some of them are seen to have a central nucleus of dark colour and irregular shape, but none of them present any indication of organic structure or radiated crystallization. If the residue, after having been digested in caustic potash, be washed by decantation, there remains a small number of microscopic crystals; some of these, which are white, are quartz, and others, which are black, and acutely pyramidal, consist chiefly of titanic acid." ‡

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* *Proc. Geol. Soc. Yorkshire, vol.* iii., 1856, *p.* 457.

† *See* Memoirs of the Geological Survey, "Iron Ores of Great Britain," Pt. 1, page 97, 1856; and also *Quart. Journ. Geol. Soc.*, vol. xii., p. 357.

‡ "Professor Miller, of Cambridge, succeeded in measuring some of the angles of the crystals containing titanic acid, and found that they correspond to similar angles in anatase. The green colour of the ore seems to be due to a silicate containing peroxide and protoxide of iron, but this could not be exactly determined, because it was not found possible to dissolve out the carbonates without acting at the same time upon the silicate of iron."

The following analysis was also made by Mr. Dick at the time of drawing up this description:—

Protoxide of iron	39·92
Peroxide of iron	3·60
Protoxide of manganese	0·95
Alumina	7·86
Lime	7·44
Magnesia	3·82
Potash	0·27
Carbonic acid	22·85
Phosphoric acid	1·86
Silica, soluble in Hydrochloric acid	7·12
Sulphuric acid	trace.
Bisulpide of iron	0·11
Water, in combination	2·97
Organic matter	trace.
Insoluble residue (of which 0·98 is soluble in dilute caustic potash, and consists chiefly of oolitic concretions)	1·64
	100·41
Iron, total amount	32·62

INSOLUBLE RESIDUE

Silica	1·50
Alumina, with a trace of peroxide of iron	0·10
Titanic acid, about	0·03
Lime	trace.
	1·63

This, from the high per-centage of iron, is evidently a specimen from Eston Hill, probably near the outcrop.*

Whinstone.—Although the vast ironstone industry naturally overshadows all others, still a considerable amount of employment is given in quarrying and mining the "whin" of the Cleveland Dyke. This is mostly broken up in the district for road-metal and small paving-setts, and is used for most of the main roads of the district. It is also sent away by train to great distances. The Moor Grit, where of a hard glassy nature, is also used for road-metal in the immediate neighbourhood of its outcrop.

Building stone.—The freestones of the Oolite are much used as local building stones, but, as a rule, they are not suitable for viaducts or any high structure where they will have to bear a great pressure, as they contain a deal of decomposed felspathic matter.

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* For further information as to the chemical constitution of the seam, *see* J. L. Bell on the Cleveland Ironstone, Colliery Guardian, Vol. XXIII., p. 132, 1863; W. Crowder, Edinburgh New Phil. Journal, Ser. 2, Vol. III., p. 286, 1856; John Marley, Cleveland Ironstone, Trans. N. of England Inst. of Mining Engineers, Vol. V., p. 165, 1857; John Pattinson, British Assoc. Reports, 1863, and Trans. S. Wales Inst. Eng., Vol. VI., p. 284; also Dr. Percy's Metallurgy, Iron and Steel, p. 223.

Brick Clays.—Brickmaking has been carried on to a great extent in this district, the chief material used being the clays of the Glacial Series. Of these, by far the best is the laminated clay occurring above the Lower Boulder Clay. It is extensively worked near Guisborough for bricks, tiles, and drain pipes; but the same beds are used to a far greater extent near Middlesbrough, just west of this area, the greater part of the town being built of bricks made from the laminated clay.

The Upper Boulder Clay being of a light nature, and nearly free from stones, has also been used for brickmaking; but the yards are scattered over a wide area, and only supply the small local demand.

A very fine class of bricks, &c. is made from the shales or fireclays of the Oolitic Series, as may be seen near Egton. There are extensive works of this class at Commondale, and still more recently, operations on a large scale have been begun on the north-west point of Normanby Hill.

Jet.—Among the industries now nearly extinct is that of jet-mining (*see* pp. 32–34).* The innumerable tip-heaps that line the entire cliff face and the escarpment of the Lias, wherever the latter is free of drift, show how extensively this mineral has been sought for; but as the more accessible places have been worked out, and jet is much reduced in price, there are now only a few of the levels in which mining is going on.

Alum.—The great alum industry is now almost a thing of the past, but it has been the means of bringing to light so many fine examples of Saurians, and still affords the opportunity of collecting so many of the characteristic fossils, that a reference to it does not seem out of place here. A site was chosen in which the Upper Lias escarpment was free of drift, and the hill slope of such a nature as to permit a large excavation to be made in the Alum Shale without removing much bearing of the Oolite Sandstones above. The Alum Shale which was dug out contains a considerable amount of finely-distributed pyrites, as may be inferred by the yellow edges of weathered fragments of the rock. A layer of brush wood, considerable quantities of which may still be seen growing in the neighbourhood of several of the old works, was spread over the ground, and on this the shale was laid, then more wood, and then shale again, till the whole was of the dimensions required. This heap was set light to, and the pyrites caused it to smoulder slowly for a long period, care being taken not to allow the whole to attain too high a temperature. The result of the process was to form the exceedingly soluble Sulphate of Alumina in the calcined shale, and the latter was soaked in steeping pits till the former was dissolved out. The liquor was then sent along wooden troughs to the precipitating and boiling houses, where an alkali, usually potash, was added.

* Quite recently this industry seems to have acquired a fresh lease of life. A good account of "Whitby Jet and its Manufacture" was given by Mr. J. Bower, in *Journ. Soc. Arts*, Vol. xxii., pp. 80–87, 123; 1874.

This formed the double Sulphate of Alumina and Potash, much more easily precipitated by boiling. After precipitation it was re-dissolved, and left to crystallise out in casks. At Boulby the old works are still in existence, though they are rapidly falling into decay. In the latter days of these works coal was brought by sea, and hauled up a shaft connected by a tunnel with the shore, the coal being used for calcining the shale.

The chief cause of the dying out of the industry was the discovery of a far cheaper process of making alum from the coal shales turned out in coal mining.

Coal.—The small seam of coal under the Grey Limestone has been sufficiently described already (p. 48). It has only been worked to any extent in the extreme south-central part of this area, forming a portion of the south Moorland district in which this coal attains its maximum development. So many borings have been made through the horizon of it, that there is no reason to suppose that it is well developed elsewhere in North Cleveland.

Salt.—This has recently been proved to exist at the base of the New Red Series at Eston Station (*see* p. 4).

Soils.—The greater part of this area being covered by glacial deposits, chiefly Boulder Clay, the soil is mostly heavy and wet. Where however the surface is formed of the Middle Glacial sands and gravels, some fairly good light land is found suitable for root crops. There is a large spread of such beds on the central part of the watershed, but some of this area is probably at too great a height for cultivation. There seems, however, no reason why a large part of Wapley and Rousby Moors should not be reclaimed. Where the Oolite sandstones come to the surface, as at Rousby, they make a light soil; but the shales between the Cornbrash and Grey Limestone are particularly cold, wet, and heavy. A large spread of these occurs near Egton, and the land being useless for any other purpose has recently been planted. The appearance of the young trees is not promising, and shows only too plainly the poverty of the soil. Of the Lias, only the upper beds have any extensive drift-free outcrop; but these form so steep a bank that they are in general planted. Magnificent examples of such woods are to be seen on the south side of Guisborough.

The main area, which consists of clay and has to be extensively drained, falls naturally into two divisions—the great table land or upland, and the plains of the Guisborough and Redcar districts. There is a far greater difference than might be expected in the climate of the two areas; in the higher land, the nights are much colder, and the weather wetter, than in the lowlands. The ripening of corn crops is in consequence very precarious in the former district, and much land has lately been laid down to permanent pasture.

In the plains some fine corn crops are obtained, Middlesbrough affording large quantities of manure for the arable lands; still, even in this case, foreign competition is so keen, that there is an increasing tendency to augment the area of grazing land.

APPENDIX.

List of some of the Works on the Geology, &c. of Cleveland.

1679.

Colwal, D. An Account of the English Alum Works. *Phil. Trans.* Vol. XII., No. 142, p. 1052.

1759.

Chapman, W. Fossil Bones of an Alligator found near Whitby. *Phil. Trans.* Vol. I., Part 2, p. 688.

1779.

Charlton, L. The History of Whitby, &c. *4to. York.*

1794.

Tuke, J. General View of the Agriculture of the North Riding of Yorkshire. *4to. Lond.*

1810.

Farey, J. Geological Relations and Character of the Alum Shale. *Phil. Mag.* Vol. XXXV., p. 256.

1812—1815.

Sowerby, J. The Mineral Conchology of Great Britain. Vol. I. 8vo. *Lond.* Vol. II. 8vo. *Lond.* (1816).

1817.

Sutcliffe, J. Short Introduction to the Study of Geology (Yorkshire Iron Ores, p. 31). 8vo. *Lond.*

Young, G. A History of Whitby. 8vo. *Whitby.* (See also *Phil. Mag.*, Vol. LI., p. 206; 1818).

1819—1821.

Sowerby, J. Mineral Conchology of Great Britain. Vol. III. 8vo. *Lond.*

1821.

Smith, W. Geological Map of Yorkshire. 4 sheets.

Winch, N. J. Observations on the Eastern Part of Yorkshire. *Trans. Geol. Soc.* Vol. V., p. 545.

Young, G. Account of a Singular Fossil Skeleton discovered at Whitby. *Mem. Wernerian Soc.* Vol. III., p. 450.

1822.

WINCH, N. J. On Blocks of Granite, Syenite, &c., embedded in Diluvium. *Ann. of Phil. Ser.* 2. Vol. III., p. 373.

———— Geology of the Eastern Part of Yorkshire. *Ibid.* p. 374.

YOUNG, G. and J. BIRD. A Geological Survey of the Yorkshire Coast. 4to. *Whitby.* Ed. 2, in 1828.

1824.

SEDGWICK, A. On the Phenomena connected with some Trap Dykes in Yorkshire and Durham. *Trans. Cam. Phil. Soc.* Vol. II., Part I., p. 21, and *Phil. Mag.* Vol. LXVII., pp. 211, 249; 1826.

YOUNG, G. A Picture of Whitby and its Environs (Geological Observations). 8vo. *Whitby.*

1824—1825.

SOWERBY, J. Mineral Conchology of Great Britain. Vol. V. 8vo. *Lond.*

1825.

SEDGWICK, A. On the Origin of Alluvial and Diluvial Formations. *Ann. of Phil.* Ser. 2. Vol. IX., p. 241; and Vol. X., p. 18.

YOUNG, G. Account of a Fossil Crocodile recently discovered in the Alum Shale near Whitby. *Edin. Phil. Journ.* Vol. XIII., p. 76. (See also *Ann. of Phil.* Ser. 2. Vol. IX., p. 469.)

1826.

SEDGWICK, A. On the Classification of the Strata which appear on the Yorkshire Coast. *Ann. of Phil.* Ser. 2. Vol. XI., p. 339.

1826–29.

SOWERBY, J. & J. D. Mineral Conchology of Great Britain. Vol. VI. 8vo. *Lond.*

1827.

PHILLIPS, JOHN. On the Direction of the Diluvial Currents in Yorkshire. *Phil. Mag.* Ser. 2. Vol. II., p. 138.

1828.

PHILLIPS, JOHN. Remarks on the Geology of the North Side of the Vale of Pickering. *Phil. Mag.* Ser. 2. Vol. III., p. 243.

1829.

PHILLIPS, JOHN. Illustrations of the Geology of Yorkshire. 4to. *York.* Ed. 2. 1835. Ed. 3. 1875.

1831.

WITHAM, H. Observations on Fossil Vegetables, &c. 4to. *Edin. and Lond.*

1832.

MURCHISON, R. I. On the occurrence of stems of Fossil Plants in vertical positions in the Sandstone of the Inferior Oolite of the Cleveland Hills. *Proc. Geol. Soc.* Vol. I., p. 391.

1836.

WILLIAMSON, W. C. A Notice of two hitherto undescribed Species of Radiaria, from the Marlstones of Yorkshire. *Mag. Nat. Hist.* Vol. IX., pp. 425, 554.

1837.

CHARLESWORTH, E. Illustrated Zoological Notices. 2. On the recent Discovery of a Fossil Crocodile at Whitby. *Mag. Nat. Hist.* Vol. X., p. 531.

HUNTON, L. Remarks on a Section of the Upper Lias and Marlstone of Yorkshire. *Trans. Geol. Soc.* Ser. 2. Vol. V., p. 215.

WILLIAMSON, W. C. On the Distribution of Fossil Remains on the Yorkshire Coast. *Trans. Geol. Soc.* Ser. 2. Vol. V., p. 223.

1840.

OWEN, R. Report on British Fossil Reptiles. *Brit. Assoc. for* 1839, p. 43.

1845.

CHARLESWORTH, E. Note on the Discovery of a large Specimen of Plesiosaurus, found at Kettleness, on the Yorkshire Coast. *Rep. Brit. Assoc.* for 1844. *Trans. of Sections*, p. 49.

1847.

CHARLESWORTH, E. New Species of Pentacrinus in the Lias of Yorkshire. *Lond. Geol. Jour.*, pp. 96, 131, pl. IX.

1849.

WILLIAMSON, W. C. On the Scaly Vegetable Heads or Collars from Runswick Bay. *Proc. York. Phil. Soc.* Vol. I., Part I., p. 45.

YATES, J. Notes on Zamia gigas. *Proc. York. Phil. Soc.* Vol. I., Part I., p. 37.

1851.

DAVIDSON, T. Monograph of British Oolitic and Liassic Brachiopoda, No. 1. *Palæontograph. Soc.*

1852.

MAY, C. Iron Ore near Middlesbro'-on-Tees. *Proc. Inst. Civ. Eng.* Vol. XI., p. 28.

1855.

SIMPSON, M. The Fossils of the Yorkshire Lias. 12*mo*. *Lond.* Ed. 2 in 1884.

WILLIAMSON, W. C. On the Restoration of Zamites gigas from the Lower Sandstone and Shale of the Yorkshire Coast. *Rep. Brit. Assoc. for* 1854. *Trans. of Sections.* p. 103.

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56. Haggate.	86. Adlington.	
57. Winewall.	87. Bolton-le-Moors.	106. Liverpool.
61. Preston.	88. Bury, Heywood.	107. Prescott,
62. Balderstone.	89. Rochdale, &c.	108. St. Helen's.
63. Accrington.	92. Bickerstaffe.	109. Winwick.
64. Burnley.	93. Wigan.	111. Cheedale.
65. Stiperden Moor.	94. West Houghton.	112. Stockport.
69. Layland.	95. Radcliffe.	113. Part of Liverpool.
70. Blackburn.	96. Middleton, Prestwich.	
71. Haslingden.		
72. Cliviger, Bacup.		

Durham.

1. Ryton.	6. Winlaton.	11. Ebchester.
2. Gateshead.	7. Washington.	12. Tantoby.
3. Jarrow.	8. Sunderland.	13. Chester-le-St.
4. S. Shields.	9. ———	16. Hunstanworth.
5. Greenside.	10. Edmondbyers.	17. Waskerley.

Durham—*continued.*

Sheet.	Sheet.	Sheet.
18. Muggleswick.	25. Wolsingham.	38. Maize Beck.
19. Lanchester.	26. Brancepeth.	41. Cockfield.
20. Hetton-le-Hole.	30. Benny Seat.	42. Bp. Auckland.
22. Wear Head.	32. White Kirkley.	46. Hawksley Hill Ho.
23. Eastgate.	33. Hamsterley.	52. Barnard Castle.
24. Stanhope.	34. Whitworth.	53. Winston.

Northumberland.

44. Rothbury.	80. Cramlington.	98. Walker.
45. Longframlington.	81. Earsdon.	101. Whitfield.
	82. NE. of Gilsland.	102. Allendale Town.
46. Broomhill.	83. Condley Gate.	
47. Coquet Island.	87. Heddon.	103. Slaley.
54. Longhorsley.	88. Long Benton.	105. Newlands.
55. Ulgham.	89. Tynemouth.	106. Blackpool Br.
56. Druridge Bay.	91. Greenhead.	107. Allendale.
63. Netherwitton.	92. Haltwhistle.	108. Blanchland.
64. Morpeth.	93. Haydon Bridge.	109. Shotleyfield.
65. Newbiggin.	94. Hexham.	110. Wellhope.
72. Bedlington.	95. Corbridge.	111. Alleuheads.
73. Blyth.	96. Horsley.	112.
	97. Newcastle.	

Cumberland.

55. Searness.	65. Dookraye.	74. Wastwater.
56. Skiddaw.	69. Buttermere	75. Stouethwaite Fell.
63. Thackthwaite.	70. Grange.	
64. Keswick.	71. Helvellyn.	

Westmorland.

2. Tees Head.	12. Patterdale.	25. Grasmere.
6. Dufton Fell.	18. Near Grasmere.	38. Kendal.

Yorkshire.

7. Redcar.	116. Conistone Moor.	260. Honley.
9. ———	133. Kirkby Malham.	261. Kirkburton.
12. Bowes.		262. Darton.
13. Wycliffe.	184. Dale End.	263. Hemsworth.
20. Lythe.	185. Kildwick.	264. Campsall.
24. Kirkby Ravensworth.	200. Keighley.	272. Holmfirth.
	201. Bingley.	273. Penistone.
25. Aldborough.	202. Calverley.	274. Barnsley.
32. Whitby.	203. Seacroft.	275. Darfield.
33. ———	204. Aberford.	276. Brodsworth.
38. Marske.	215. Peeke Well.	281. Langsell.
39. Richmond.	216. Bradford.	282. Wortley.
46. ———	217. Calverley.	283. Wath upon Dearne.
47. Robin Hood's Bay.	218. Leeds.	284. Conishorough.
	219. Kippax.	287. Low Bradford.
53. Downholme.	231. Halifax.	288. Ecclesfield.
68. Leybourne.	232. Birstal.	289. Rotherham.
82. Kidstones.	233. East Ardsley.	290. Braithwell.
84. E. Witton.	234. Castleford.	293. Hallam Moors.
97. Foxup.	246. Huddersfield.	295. Handsworth.
98. Kirk Gill.	247. Dewsbury.	296. Laughton-en-le-Morthen.
99. Haden Carr.	248. Wakefield.	
100. Lofthouse.	249. Pontefract.	299. ———
115. Arncliffe.	250. Darrington.	300. Harthill.

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